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Zastosowanie robota IRb 60 do czyszczenia odlewów
etap 10
Koordynacja prac tematu w zakresie współpracy z ASEA

Tłumaczenie na język angielski sprawozdań z prac etapów 6,7 i 13 /obszernych fragmentów/

Zleceniodawca
Praca własna

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Praca zawiera:		**Rozdzielnik - ilość egz:** 3	
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fotografii		**Egz. 3**	OAK 7
tabel		**Egz. 4**	
tablic		**Egz. 5**	
załączników		**Egz. 6**	

Nr rejestr. 4745

Analiza deskryptorowa

ROBOTY PRZEMYSŁOWE ADAPTACYJNE :
ZASTOSOWANIA i BADANIA

Analiza dokumentacyjna

Dokumentacja zawiera sprawozdanie z badań robota adaptacyjnego z oprzyrządowaniem , przeznaczonego do oczyszczania odlewów żeliwnych metodą szlifowania. Opracowanie wykonano w języku angielskim w celu przekazania do ASEA.

Tytuły poprzednich sprawozdań

"Wykonanie i rozruch instalacji hydraulicznej w MERA PIAP"
"Analiza czystości patentowej " nr rej. 4565 .
"Badania makietowe instalacji i próby czyszczenia odlewów" nr rej.463
"Przygotowanie instalacji do praktycznego czyszczenia"
"Próba skonstruowania nowej obrotnicy dolnej" nr rej. 4647

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Test of working range of IRb 60 with the hydraulic equipment mounted on it

Test was performed on the laboratory installation /fig.1/ with :

- the robot , equippped with the grinding head ,
- the torque-measurement version of the grinding head was used ,
- the flat grinding disk , Ø 350x40 , was on the shaft of the grinding unit ,
- the hydraulic installation consisted of the flat rotating swivel for the v motion.,

The idea of this test was to position the robot axles θ and α in seven limit positions , according to the ASEA drawing no. 6397 001 - CN /fig. 2/ .

The assumed criterion was to reach any limitation in t motion, next in θ or α motions keeping full range motion / $\pm 180^{o}$/ in v rotation.

Three auxiliary indicating scales were attached to the housings of θ , α and t axles. Indicators on the rotating parts of each axle pointed angles θ_n , α_n and t_n. The "n" indexed values were re-counted relatively to the vertical and level / and then indexed with "r" / :

$$\theta_r = \theta_n + 51^{o}$$

$$\alpha_r = \theta_n + \alpha_n + 6^{o}$$

$$t_r = \theta_n + \alpha_n + t_n - 75^{o}$$

The values θ_r , α_r and t_r were compared with the values θ, α and t for each position acc. to the technical specification of IRb 60.

The test shows robot is able to move in the whole range of both θ and α motions. Some limitation was shown in wrist bending t /fig. 3/ . The reasons of it are as follows :

- the wrist swivel interferes with the upper arm of robot ,
- there is the menace of cutting of pipes or robot arm by the grinding wheel / Ø 350 / in some positions of wrist ,
- the hydraulic motor pipes interfere with the column of robot / fig. 3 , pos. 3/ ,
- the grinding head interferes with the floor /fig. 3,pos. 2/,
- the total length of pipes between upper swivel and wrist

swivel is too small - it affects the robot in far down positions , near to pos. 2 / fig. 3/ .
The upper swivel / fig. 1/ allows robot to work in the whole range of rotation φ. Two limitations of φ motion appears in our laboratory installation :

- some parts of installation are placed within the robot working range ,
- the support of the upper swivel is mounted too close to robot in the dead area of φ motion ; the pipes mounted by the arms of robot collide with this support.

Both limitations are not severe as they are caused by the little space in laboratory room and they are easy to eliminate in plant installation.

In conclusion we can accept the following range of IRb 60 motions in our installation :

- column φ rotation range : $\pm 155^{\circ}$ / $\pm 165^{\circ}$/ ,
- lower arm θ movement range : $-20^{\circ} \div +50^{\circ}$ around vertical pos. ,
- upper arm α movement range : $+10^{\circ} \div -55^{\circ}$ around horizontal pos.,
- wrist movement range , vertical bending t : $+50^{\circ}$ /$+75^{\circ}$/ $\div$ -85°/ -120°/ from horizontal position ,
- wrist movement , turning v : $\pm 180^{\circ}$.

Locally the values φ and t may increase over the limits , till the values in brackets.

The analysis of a/m limitations shows the ways how to eliminate some of them in the future plant installation.
To move the support of the upper swivel appr. 1 m away from the robot or to mount this swivel to the ceiling of ev. housing of the plant installation will allow to move the robot in full range of φ rotation.
A little elongation of the pipes mounted between the swivels / fig. 1/ or lowering the upper swivel will eliminate some limitation around pos. 2.
The full utilisation of the handling capacity in far lower area of the working range / fig. 3 pos. 2/, will be possible when robot will be placed appr. 200 mm over the floor.
The smaller diameter of the grinding wheel, the smaller t motion limitation.

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The new , cylindrical-shape wrist swivel will decrease / appr. 7^{o} / the t motion limitation in some positions /fig.4/ .

Tests of three versions of the adaptive sensor and selection the most suitable one for laboratory experiments of castings cleaning

Initially the load torque on the shaft of the grinding disk was taken as a measure of the load on the tool.
Two sensors for torque measurement were designed.
First solution is based on the measurement of the torque generated by the reaction forces of the constraints supporting the tool on the robot arm.
The second , indirect solution of sensor is based on the measurement of the pressure of feeding oil to the hydraulic motor.

The third version of adaptive sensor was designed on request of ASEA. This solution enables measurement of 2 ÷ 3 components of load force on the tool.
All versions were tested in the laboratory casting cleaning installation , in MERA PIAP /fig. 1/.

Testing system for adaptive sensors enables simultaneous measurement and recording of / fig. 5/:

- pressure of feeding oil ,
- reaction torque of constraints or tangential and radial forces on the grinding tool ,
- two perpendicular forces on the fixture of the machined detail.

The ideas of grinding heads with different sensors are shown on fig.8 , 13 , 23 .
The pressure sensor as well as torque or force sensors are connected to the separate electronic boards , each one with some outputs. First output gives an analogue voltage signal proportional to pressure /or torque or force/ . This signal is recorded on the 6-channel recorder.
Each of next 1 ÷ 3 adaptive outputs gives three level signal acceptable for the adaptive control program of IRb. The system of potentiometers on the associate electronic boards allow the setting of switching points of the adaptive signal for

each output. Each adaptive output can work on different levels of the same analogue signal from measuring unit.
The settings of switching points were selected practically during experiments to obtain the best results of casting cleaning.

The preliminary tests showed some malfunctions of the sensors and some improvements had to be done.

The grinding samples were fixed in the fixture mounted on the force sensor called "universal head"/fig. 6/ .
It is the sensor for measurement of two or three components of force. /One unit of this universal head was sent to ASEA for testing several months ago/. The universal head was utilized for measurements of the forces on the grinding wheel. The output signals from this head copy tangential and radial forces when grinding. The signals were recorded on a/m recorder.

The problem arose how to connect the sensor mounted on the grinding head to the robot. The accepted solution enables full mobility of the tool and it protects the wire against mechanical damage / fig. 7/.

The grinding head with torque sensor /fig. 8/ .

The first tests showed that the preliminary assumptions of forces , power and pressure when grinding were overestimated. The signals were too low. To enlarge the signals the intermediary spring of torque sensor was replaced by stiffer one.

The analysis of graphs of torque signals plotted on recorder:

- the negative torque appeared when the unloaded grinding head was running ; the value of this torque was comparable with the torque during grinding / fig. 9a/; the negative torque was created by the flexible pipes feeding the oil to the motor ; they were inflected and acted as springs when the pressure in installation grew up ; the redesign of the end pieces of the pipes straightened the pipes and the negative torque was reduced to the reasonable level / fig. 10a / .
- the redundant hysteresis was observed / fig. 9 b/. To remove this hysteresis the return spring /fig. 8/ was fixed on its

position by means of two conical-shape pins on each end of the spring. Unfortunately it didn't cancel the discussed hysteresis / fig. 12 a/. Maybe it was caused by the bearings of the housing of the grinding head within the fixture.
- the significant influence of the grinding head position on the value of the output torque signal was a great surprise / fig. 10/. This situation was observed when the shaft was in rest as well as during no-load running of the grinding head. At the same time , during the no-load running of the shaft , the signal from the pressure sensor was completely unchanging.

The attempt was made to eliminate two main disadvantages of the first design of the grinding head with torque sensor. The new holder of the grinder was designed /fig. 13/.
The tool is suspended within the holder by means of 4 flat springs. The idea was to pass the axis of rotation of the grinder within the holder through the centre of gravity of the whole tool. This solution of the grinding head was intended to eliminate the dependence of the torque signal upon the grinding head position and also to eliminate the torque caused by the weight of unsymmetrical grinding head in its previous version. The exclusion of the bearings should eliminate the hysteresis mentioned above as well. The test showed this new version maintained the dependence of the signal upon the position of the grinding head / fig.15 i 16/.
Then the tests of the force sensor itself , utilized for torque measurement within the grinding head, were made. These tests showed inherent dependence of the signal upon the position of the sensor / fig. 18/. The max. difference between signals in several positions of sensor is appr. 1,5 div.
It is equivalent of appr. 2,5μm /fig. 19/ displacement of the push rod of the sensor or the torque appr. 1 kGm /fig. 14/ on the shaft of the grinder.

The signal obtained from the "torque" grinding head with the limp intermediary spring is very low /fig. 17 a/. The signal grows up for the stiffer spring / fig. 17 b/.Unfortunately the parasitical " positioning" signal grows up as well. The new intermediary spring was designed in virtue of the tests of the sensor /fig. 18 ÷ 20/. This spring will eliminate the negative influence of cross forces acting on the sensor mounted within grinding head.

The general problem of version of the qrinding head was the dependance of the torque signal upon the position of the grinding head.

The difference between the values of the signal /the error signal/, from the extreme positions of the qrinding head were appr. 5x bigger then the medium working signal when grinding.

It was important to find the reason of this error signal.

Some reasons of the origin of this error signal were considered. Two of them were choosen, after some observations, as the most likely :

- the flexibility of the sleeve and the foundations of the suspension springs ;
  it would allow the little transverse dislocations of the grinder; the sensor is sensitive, in some way, for such dislocations,
- the eccentricity of the center of gravity in relation to the measuring turn axis of the grinding head, the torque created by the eccentric weight adds to the signal from the sensor.

As a matter of fact both reasons are entangled and it was not possible to manage any test to watch the pure influence of either a/m reason on the signal.

Some arrengements were made to improve this version of the grinding head to eliminate the error signal or to diminish it to the reasonable level.

First, the pusher of the sensor was redesigned fig.13a. Then it became weaker for the cross forces with the some coaxial stiffness. The sensor became less sensitive for minor transverse dislocations of the grinder.

The error signal was limited to ~64% of its previous value.

Then the rotational stiffnes of the suspension of the grinder was reduced appr.10x by means of the thinner suspension springs.

Some tests were made with the washers between the suspension springs and their foundations to eliminate the eccentricity of the center of gravity.

Finally the right intermediary spring of the sensor was choosen and the correct assembly of the whole grinding head was made. The special attention was paid to the proper fixing of the suspension springs by means of the pins.
At the end, the error signal was reduced /5x/ to the level of the medium working signal when grinding.

It seems the method was right but the effects are still not satisfactory.
Unfortunately it is impossible to continue this way of improvement of the signal performance as the strength of the pusher and suspension springs limit the changes mentioned above.

Any reinforcements of the sleeve or the foundations of the suspension springs are not possible as the robot is loaded to its limits.

The only way to the further minimization of the error signal offers the electronics associated with the torque sensor. It allows to create several adaptive sensors based on the same analogue measuring sensor signal.
It means it is possible to make similar adaptive sensors for different working positions of the grinding head /for different error signal levels/. As robot has 8 adaptive input signals and the amount of the working positions of the grinding head is practically limited, it is possible to use this solution of the grinding head with torgue measurement for the tests of adaptivity. The proper adaptive, 3 level sensor should be choosen when programming, appriopriately to the grinding head working position. Two adaptive sensors were prepared, based on the same torque signal.
The switching points of those sensors were choosen practically. All adaptive functions were tested with those sensors.

The grinding head with pressure sensor.

The pressure sensor is mounted on the stationary part of the hydraulic oil supply installation , next to the pump. The signal from this sensor was observed during testing of other sensors e.g.fig. 9, 10, 12, 17, 27.
The pressure of oil in no-load running of the grinding head is high /appr. 2 ÷ 2,5 MPa/.

The preliminary tests showed that the changes of the pressure signal are too small when grinding. Then the pressure sensor of 0 ÷ 25 MPa pressure range was replaced by another of 0 ÷ 10 MPa pressure range, well fitted for this purpose. The pressure signal had to be filtered as it was distorted by noise. The negative influence of the pump pulsation wasn't stated in the pressure signal as it wasn't possible to find it clearly in the noise. It seems that does not exist any significant delay in propagation of pressure signal in the hydraulic installation / fig. 9 c/.

Practically pressure signal has no hysteresis nor any undefined deformations. It is independent of the position of the position of the grinding head nor the movements of the axles of robot.

For calibration of the pressure sensor in the installation, the hydraulic motor was replaced by the hand operated valve. The pressure in installation was set by means of this valve / fig. 21/. The indications U of the mV-meter were written down on the graphs plotted by chart recorder.

The formula for calculating the real pressure in installation during test is :

$$P = 0,48\ P_r + 1,6\ /at/\ ,$$

where P_r it is pressure in /div/ from the graph.

The calibration of the universal head was made by weighing some known weights/fig. 22/.
The formula for calculating the real forces during tests :

$$F = 1{,}25\ F_r - 21{,}25\ /kG/\ ,$$

where F_r it is the force in /div/ from the graph.
This formula is valid for both forces / vertical and horizontal/ but only for the same fixture and the same samples.

The grinding head with the force sensor /fig. 23/.

The holder of this version of grinding head has an ability to provide it with max. 3 force sensors to measure the components of the load force on the tool.
The version taken for testing was provided with two such sensors for measuring the components of force acting in the plane of grinding disk. The calibration of this version of grinding head was made by weighing some known weights hanged on the shaft of the grinder /fig. 24,25/.

This version of adaptive sensor was so sensitive to the position of the grinding head that only few preliminary tests were made /fig. 26/.
The example of force signal when grinding is shown on fig. 27.

The selection of the sensor for the adaptive casting cleaning installation in laboratory.

The tests of all sensors showed that all of them respond to the change of load on the tool. The signals from sensors are deformed by some unknown nonlinearities but that is of no significant importance from the adaptivity point of view.
The main disadvantage is that torque sensor and , most of all, the force sensor are significantly dependent on the position of the grinding head. It sets limitations on use those signals for adaptive control of robot in its whole working range.
The signals can be used however for adaptivity "locally" , ie. during the motions when the signals of no-load running are constant due to robot axle motion.

It is possible, thanks to the associated electronics, to make several different adaptive sensors /from the robot point of view/ based on one analogue force or torque signal. It enables to have several sensors reacting similarly on the same increase of e/g.force , but on different levels of it. Then, dividing all needed motion for "local" segments makes possible to use adaptivity in full range. With no doubt , the most useful unit for laboratory tests is the pressure sensor. It has some advantages , like :

- it is sensitive enough for the changes of load on the tool,
- the output signals from the pressure transducer are repeatable and independendent on the grinding head position,
- it simplifies the design of the grinding head,
- it makes easy to join the sensor to the robot,
- it enables the measurements of the loads of the tool caused by the forces acting in the plane of the rotating disk as well as coaxially with the shaft of the tool,
- the adaptive signal is independent of the point of application of force.

We realize this sensor is suitable for short testing of adaptive performances of robot in laboratory. For the industrial applications it should be tested at least for long term stability , independence of the wearing of oil , changes of temperature and the pressure drop on the hydraulic elements during operation. The adaptive sensor based on the measurement of the pressure drop on the hydraulic motor / the difference pressure measurement/ is promising.

The tests of adaptivity and its application to cleaning of castings

For testing of tool loading during cleaning of castings, an analog measure sensors were applied. Electronic decoding system cooperates with sensors and converts analog signals to two two-state signals for robot control program. The switching levels of tresholds 1÷4 can be set up by the resistors on the interpreting system card. Levels of tresholds correspond strictly to equivalent values of the load on the tool, which is measured by the analog sensor/s/. So, tresholds setting subordinates the robot action to definite value of load , for example torque of constraints reaction during grinding.

Main task of tests it was to check, if robot can realize its adaptive functions in cooperation with designed sensors. The most explicit signals were obtained from oil pressure sensor in hydraulic installation , so this sensor was chosen for adaptivity testing.

The remaining sensors - torque and force , in their electronic construction are made in the same strain-gauge technology.
The voltage signals from the sensors are similar to the signals from pressure sensor. It makes similar the utilization of signals from those sensors by the adaptivity.
The main obstacles in replaceable treatment of all these sensors are defects in mechanical construction and dependence of the torque or force signals on the position of the tool, and/or the lack of computing power in electronics. For now these defects make impossible an achievement of proper signals , appriopriate for their explicit interpreting by adaptive program.

The tests were made with torque head , flexibly mounted on the robot. The package of cutting discs ∅ 350 was used as a grinding tool. The motor rotation was 2300 - 2100 rpm.
The cast iron pieces were ground. They were fixed in the vice on the table mounted on the universal head.

Generally , the searching functions were performed during vertical movement of grinder. The group of SEARCH functions was tested as a beginning. This group consists of five functions:

- COARSE SEARCHING,
- DELAY COARSE SEARCHING,
- SUPERVISION,
- FINE SEARCHING,
- FREE SEARCHING .

As the reaction of adaptivity on the signal of sensor is the same for first three functions , they were treated jointly as one function. So, the analysis and comparisons were made only for COARSE, FINE and FREE searchings.
Three stages were distinguished in testing of these functions:
- general familization with action of the robot when realizing each function,
- qualification of dependence of function reaction on setting of parameters,like searching speed,correction vector and so on,
- practical comparison of action of all functions.

The setting of treshold 2 /fig. 29/ on the electronics influences the actions of coarse and fine searching.
As the width of zero zone affects on the fine searching , the setting of treshold 3 is important for it as well.
The free searching is affected only by the setting of treshold 3.

Settings of tresholds were realized by potentiometers P1 ÷ P4 /respectively for tresholds 1 ÷ 4/ /fig. 5 , 29/.
The settings are determined by measuring the voltage between the fixed point a on the electronic board and the point b on slider of appropriate potentiometer.

The dependence of the switching level of pressure / and torque and vertical force from the universal head/ on the threshold 2 setting is shown on fig. 28.

Testing of function COARSE SEARCHING

QQality of positioning of the tool and grinding off the touched surface of the sample when serching are affected by the setting of treshold 2 of adaptive sensor and speed of searching.
For comparison of various tests two criteria were used.
First of them is based on valuation of average penetration of tool into the sample. This criterion is not very reliable , however,because shape of grinding disk trace on sample depends on too many factors , hard to evaluate.
The second criterion of work performed by grinding can be the area P below the diagram curve of vertical force P_z/from the universal head/,plotted on the chart recorder. It is valid under the assumption , that the same tool works the same material and tool works always in the same way on the sample , i.e. vertically down.
Increase in setting of treshold 2 causes bigger grinding off the material/fig.29/. Influence of speed on surface deformation

is hard to define, because divergent results were obtained/fig.30/. It is so far unessential as the criterion P /area below the force curve/for tests of positioning accuracy shows that accuracy of positioning decreases with the growth of searching speed.
Test of searching accuracy in dependence on searching speed, was based on searching of sample surface with various speeds v_{sz}, and then linear positioning of robot from the founded point to the contact in other point of the same surface.
Value of P for every test was the measure of searching accuracy.

Similar tests were performed with stiff suspension of grinding head on the robot.Stiffening the suspension considerably decreased dependence of searching accuracy on searching speed. It is obvious, as far less energy is accumulated during the impact of the tool on the surface of the grounded sample.

Testing of function FINE_SEARCHING

During execution of this function , after change of adaptive signal from 00 to 01 , robot stops for compensation of servo lag and then withdraws to achieve 00 state of adaptive signal.
The following factors influences on quality of positioning and grinding off the touched surface:
- setting of treshold 2 of adaptive sensor,
- speed of searching,
- the size of correction vector.

The influence of setting of treshold 2 is obvious - the greater setting the bigger pressure of tool on the sample /i.e. the finding accurs when greater load is on tool/.
The most of obtained results are not absolutely explicit except one when the deformation of the grounded off surface decreases with growth of correction vector and with decrease of searching speed. The results of searching accuracy is however surprising . Accuracy was not dependent on these two parameters, i.e. searching speed and correction vector/fig.31/.
Grinding off of the touched surface here is greater in comparison with other kinds of searching however searching accuracy is much better. It seems the problem is hidden in the flexible mounting of the tool on the robot as the robot stops for a while

on the position.Then the flexible mounting spring back causing the deeper identation.

Testing of function FREE SEARCHING

During execution of this function robot moves with speed defined by vector,robot stops when the adaptive signal will change the state from 10 to 00.
Two factors influence on quality of positioning in this case: searching speed and setting of treshold 3. For comparision with other kinds of searching the same settings of treshold 3 were applied as for treshold 2 for preceding functions.
The tests shows the growth of setting of treshold 3 causes bigger grinding off the touched surface.The grinding off effect tends to settled value with the growth of searching speed/fig.32/. It should be another effect of flexible suspension of the grinding head on robot.
In testing of searching accuracy with a/m method various results were obtained. The estimation of some tests shows the very poor accuracy of this kind of searching, much worse than in other kinds of searching. However , in one test accuracy was comparable with the one obtained in coarse searching.
The aproximate values of e.g. speed of robot movements for different experiments/with different robot programs/ can cause some divergence of analyzed results.

Summarizing: robot reacts correctly in cooperation with the pressure sensor when realizing the searching functions.Difficulties in defining of measurable criteria of machining parameters in robot work are originated from too poor measuring instrumentation of the experimental installation and the lack of practical knowledge of grinding process. Maybe longer series of tests would make possible to define some more accurate criteria. The change of used pressure sensor for another one , more sensitive,was a result of the performed tests. The new pressure sensor allowed better cooperation of robot with it,especially better repeatibility of action of robot for the same pressure.

Testing of function VELOCITY CONTROL

For testing of funtion VELOCITY CONTROL the iron sample with a serrate shape was prepared. Movement of the robot was performed crosswise to the tooth space. Setting of switching from signal state 00 to 01 was 2,0mV. Switching of adaptive action to slower movement of robot occured when the grinding disk haves been plunged appr. 3mm in the sample. Some switching "instability" was observed , i.e. repeatadly switching between faster to slower movements of robot.The setting of proper hysteresis on treshold 2 stabilised the process.
The test confirmed completely a possibility of application of function VELOCITY CONTROL for grinding of castings.
The swithing load on the tool can be set by means of potentiometer on treshold 2 and should be defined experimentally for proper grinding disk, kind of cast , cleaning requirements and so on, with the help of technologists.

Some planned tests were not made e.g. the dependence of the load of the tool on the geom. dimensions of the grinded layer or on the grinding speed, as they need a proper grinding tool. They are left till the delivery of such tool.

Testing of function CONTOURING

This test was performed on the arc-shape sample and then on the fragment of real cast with spherical shape.Correction vectors were programmed approximately perpendicularly to basic movement. For obtaining of proper surface finish,i.e. small cutting in of disk in material , the settings of tresholds defining switching of positive and negative correction were changed. The values of treshold 3 equal to 1,9mV and of treshold 2 equal to 1,95mV were chosen. For these values of tresholds contouring of the surface of casting was performed, The correction vectors were defined appr. in every 40mm. Speed of the basic movement was appr. 3 mm/s, corrective speed was appr. 2 mm/s. Contouring was performed properly i.e. on the whole length of the sphere approximately the same grinding depth of 0,5mm was obtained. This depth can be changed by means of treshold 2 and 3 settins

without any corrections in program , as they define the adaptive contouring action of the robot. The positive and negative corrections were observed during contouring/fig. 33/.The switchings occures in every 3 - 4 seconds.
The first tests made it clear that it is hard to check the magnitude of correction vectors , as the minimum limit value of corr. vector exist.Below this limit contouring doesn't work i.e. when contouring, only basic movement is performed without any correction , regardless of sensor state. This limit value of correction vector is hard to define as it vary from position of robot to position.The problem was solved in program by introducing the instructions TIME CORRECTION before and after each definition of correction vector.Local limit value of correction vector was looked for by using the correction of time in the definition of vector. For contouring the correction vector was assumed greater than the founded limit value.

During tests the proper contouring was realized with the basic movement vector V_b and correction vector V_{cor}, as follows:

V_b	V_{cor}	$a = \frac{V_{cor}}{V_b}$
1,13	1,8	1,59
2,7	3,5	1,3
1,74	3,5	2,01
2,5	1,2	0,48

The ratio $a = \frac{V_{cor}}{V_b}$ vary from 0,48 to 2,01. As far as we understand the ASEA recomendation,this ratio should be within 0,25 ÷ 0,33. The obtained results surprised us and it seemes some misunderstanding of the contouring occures.

Proposals and recommendations concerning application of robot for cleaning of castings

Some flexibility of robot was observed.So the deflections of few important points of robot equipped with the grinding head,under

influence of force were measured. The force was applied to the grinding disk. From the grinding process point of view, the most important is the deflection of the grinding disk. The biggest deflection occurs when force acts on turning of v axis of wrist. For the force of appr. 10kG applied to the disk , the deflections are appr. 3 ÷ 3mm. It is pretty big deflection in comparison with the flaws or burr dimensions. Smaller deflections occur when loading bends the wrist /axis t/ or when the load is perpendicular to this axis. Values of these deflections are appr. 0,8 ÷ 1,8mm. The problem of deflection of the tool when grinding have to be regarded in positioning and programming. The first version of the grinding head was mounted on robot by means of elastic suspension with gum insert. It was applied to avoid a possibility of disk and/or the grinding head damage by random collision of tool with cast when grinding. The elasticy was applied to protect robot against the vibrations generated during grinding as well.
The tests showed that elasticy of robot itself and head with stiff suspension is sufficient. The "softness" of v axis can be utilized for realization of elastic pressure of the tool on the machined detail.

The occurence of momentary switching on/off of robot brakes was observed during realization of slow movements of robot. It causes jumps of robot arms when renewed switching off of brakes. It doesn't occur for the smallest speed of PTPF. It occurs only for PTPL / PTPA/ movements , beginning from certain limit speed specific to the position of the robot within its working space. Maybe this PTPL speed is smaller than any possible speed of PTPF. For horizontal movement , in some position , it occured e.g. for speed smaller than appr. 3,2mm/sec. To protect the tool , the delay time in brake control circuit was extended to 3 min. , when the tests were performed. The hardware design of the simple anti-jump circuit was prepared for the future plant application.

When tests of grinding with the first "flat" swivel, a phenomenon of jamming and even stoppage of turning of wrist /axis v/ appeared. It was caused by too great resistance to motion of this wrist swivel when oil pressure was about 2,5 MPa. The improved version of swivel has smaller resistance and a/m phenomenon doesn't appear.

Pressure of no-load running of installation depends on temperature of oil. For temperature appr. 45°C it is appr. 2,5MPa. The pressure grows up to the value of 3,2MPa when grinding. Depth of grinding is then appr. 1mm /when the width of the tool is 40mm/. The necessary power for grinding of small layer /e.g. during tests of contouring/ is appr. 6 kW.
Rotation of grinding disk in no-load running is about 2300rpm. When grinding it decreases to appr. 2000 rpm.
For smaller depth of grinding the working pressure and the needed power are certainly smaller. One should to take notice of necessity of power surplus considering of burrs or flaws of various size. So , without practical plant tests of grinding it is hard to determine the real power surplus of our installation.
Tests of grinding were made with the pack of 4 flat cutting disks, type T1, mostly because of lack of any more secure grinding disk. These disks are reinforced, they don't burst when stroken and don't "glue" during grinding the cast iron.The test with mineral disk was stopped by the burst of the disk.
Because of our tool - strange and not well selected for this purpose , all parameters found during tests became unsuitable for real casting cleaning application. They should be found once more for the proper tool.
We consider now , the best disk for grinding is the grinding wheel type T5 used as a cup type or a heavy duty cup type tool.The outer diameter should be selected individually.

The rear axle housing of heavy truck was used as an example of casting.It should not be placed symmetrically to the robot. It should be positioned in front of robot in rotary fixture, which can rotate round horizontal and vertical axis. This fixture should be placed so , that plane of robot arms is perpendicular to the longer axis of housing and this plane should cross the housing in 1/4 of the length of this housing. It will place only a half part of this long detail within the robot working area.Then the robot reach will be the most suitable. The second part of detail will be machined next , when rotating the fixture.The same program will be utilized for both parts of casting.

Conclusions

1. The tests are finished; but the real production tests of long time production should be made.
2. The tests proved the usefulness of adaptivity for casting cleaning.
3. The tests proved the usefulness of torque signals for adaptivity for casting cleaning; the only problem is of a proper design of sensor of a/m physical quantity.
4. Some malfunctions of robot were disclosed; they are of little importance but they have to be taken into consideration when programming or preparing installation.
5. Also, the installation with robot and hydraulic grinding equipment allows the plant cleaning of castings without adaptivity.
6. The installation promises the adaptive cleaning of castings in the real production using the oil pressure sensor with its associate electronics; it is ready for the long-las-ting production work when the oil temperature stabilization system will be applied.
7. The both versions of the torque sensor promise the correct cooperation with adaptive control program of robot when the dependence on sensor signal of the position of the grinding head will be eliminated or diminished. As latest tests proved it is possible by programming elimination of the different "weight" of the head in different position.
8. From the cleaning of castings point of view, the flexibility of the suspension of the grinder on the robot should be slender; the demands to enlarge this flexibility may grow up to protect robot against the vibrations generated in real casting cleaning in the production.
9. The measure of the pressure drop on the hydraulic motor should be tested as it seems to be a more stabile source of tool load signal for casting cleaning, than the pressure itself. More, such solution enable to avoid a oil temperature stabilisation system.
10. The new idea /version III/ of the torgue measurement grinding head can be prepared and checked.
11. The tests made it clear that the power applied could be reduced at least by a half.

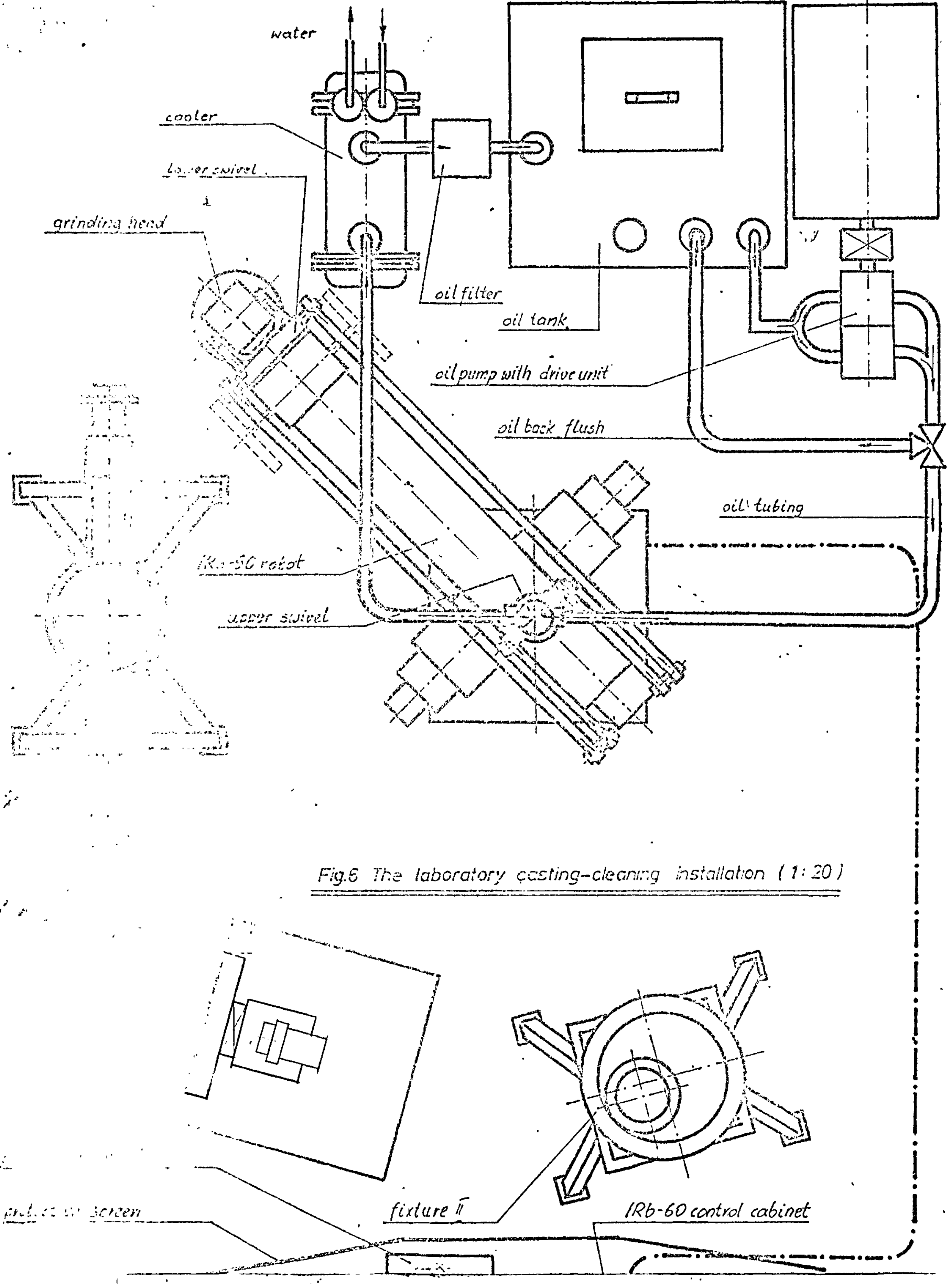


Fig. 1. The laboratory casting-cleaning installation

Bil. 2

ASEA	Industrirobot 60 kg Arbetsområde	6397 001-CN

Department	Year	Week		This document is based on licence drawing No.	Sh
YBR	75	07			

Design checked by	Accepted for prod. by	Drawing checked by	Drawn by	European projection	✓ indicates R_a in μm
Kaufmann		HK	LES		

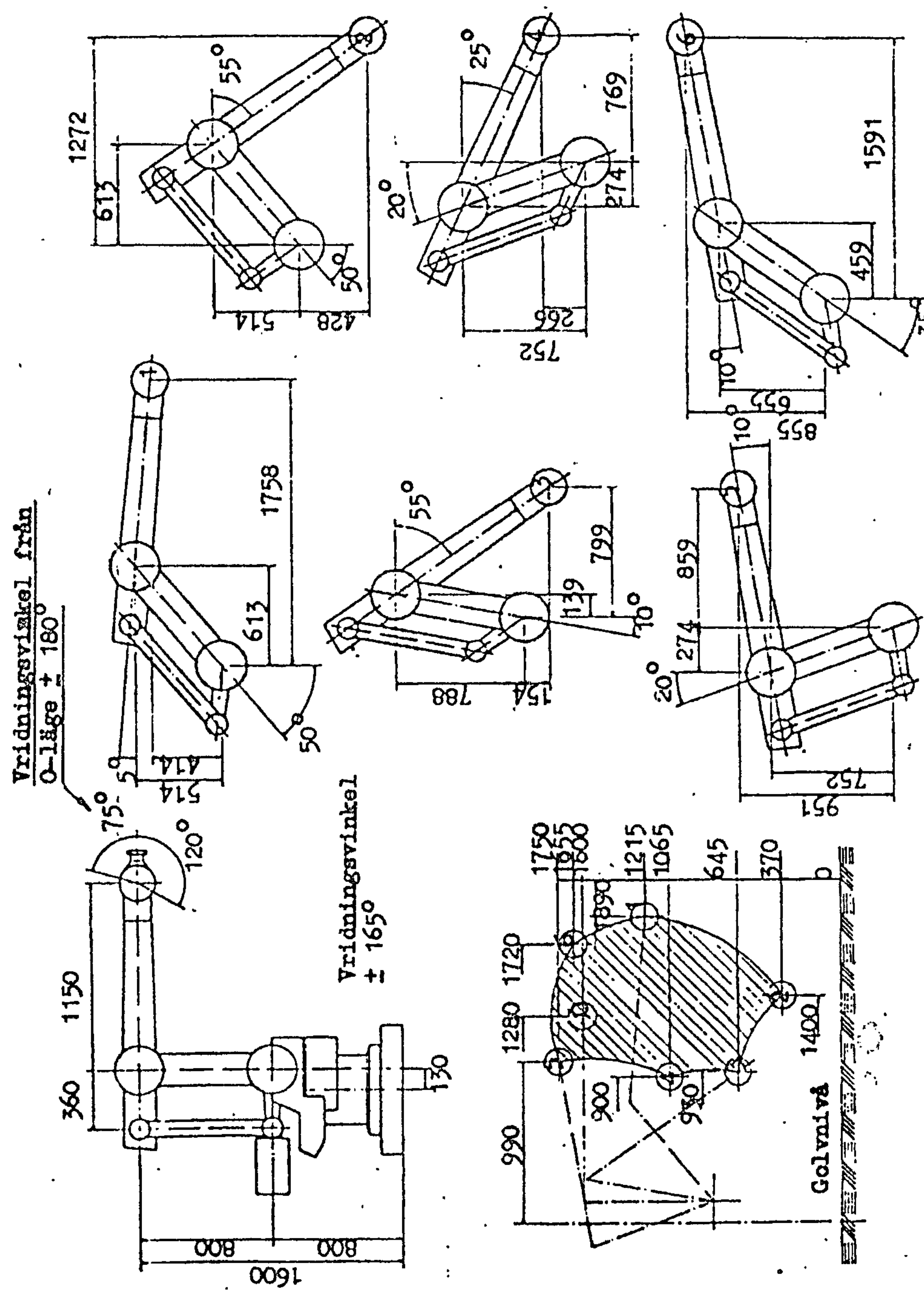
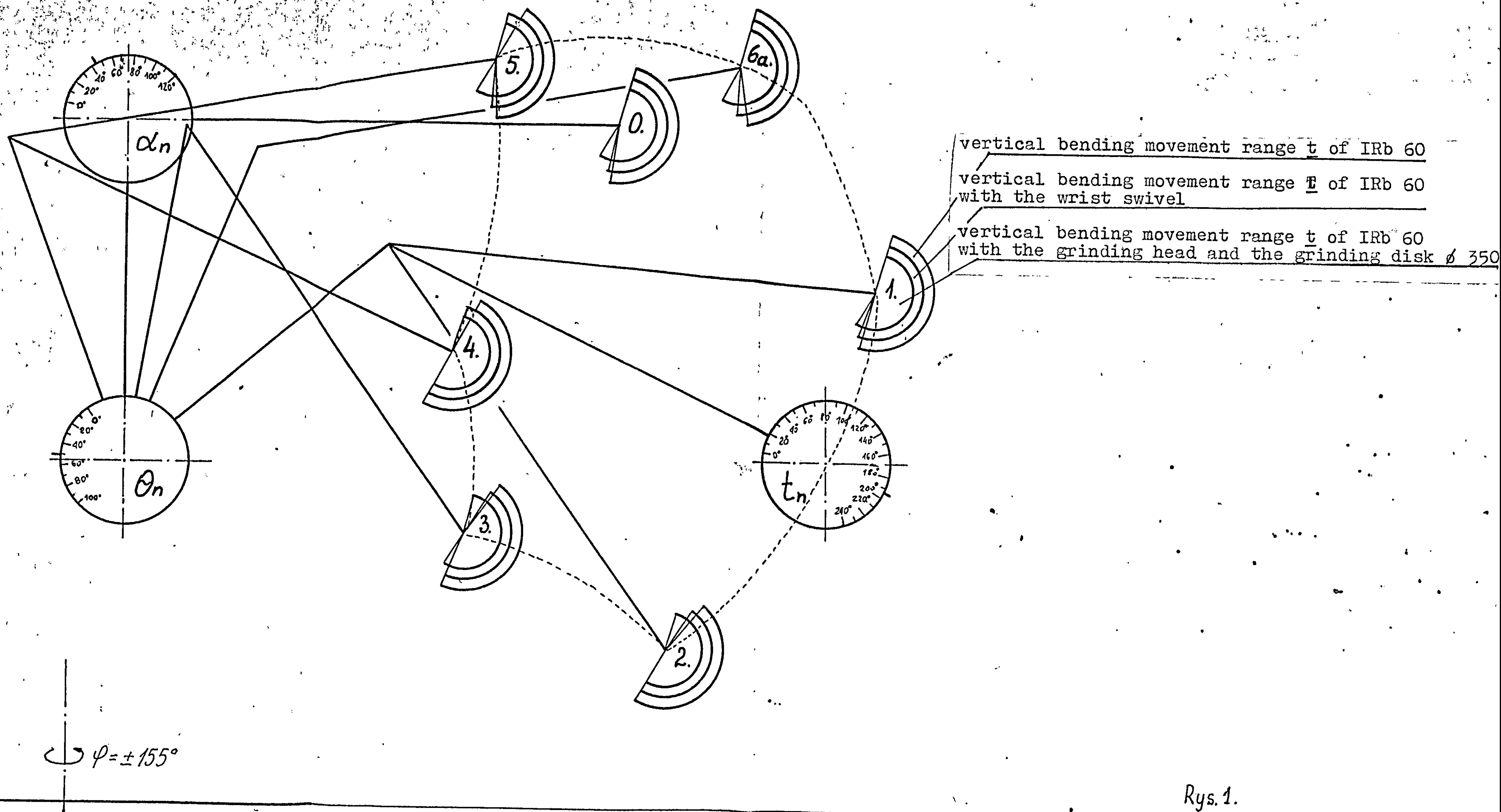


Fig. 2. IRb-60 working range

No.	Revision	Year Wk	Dept	Appd

2000 632-104 (A4) Rev.



Rys. 1.

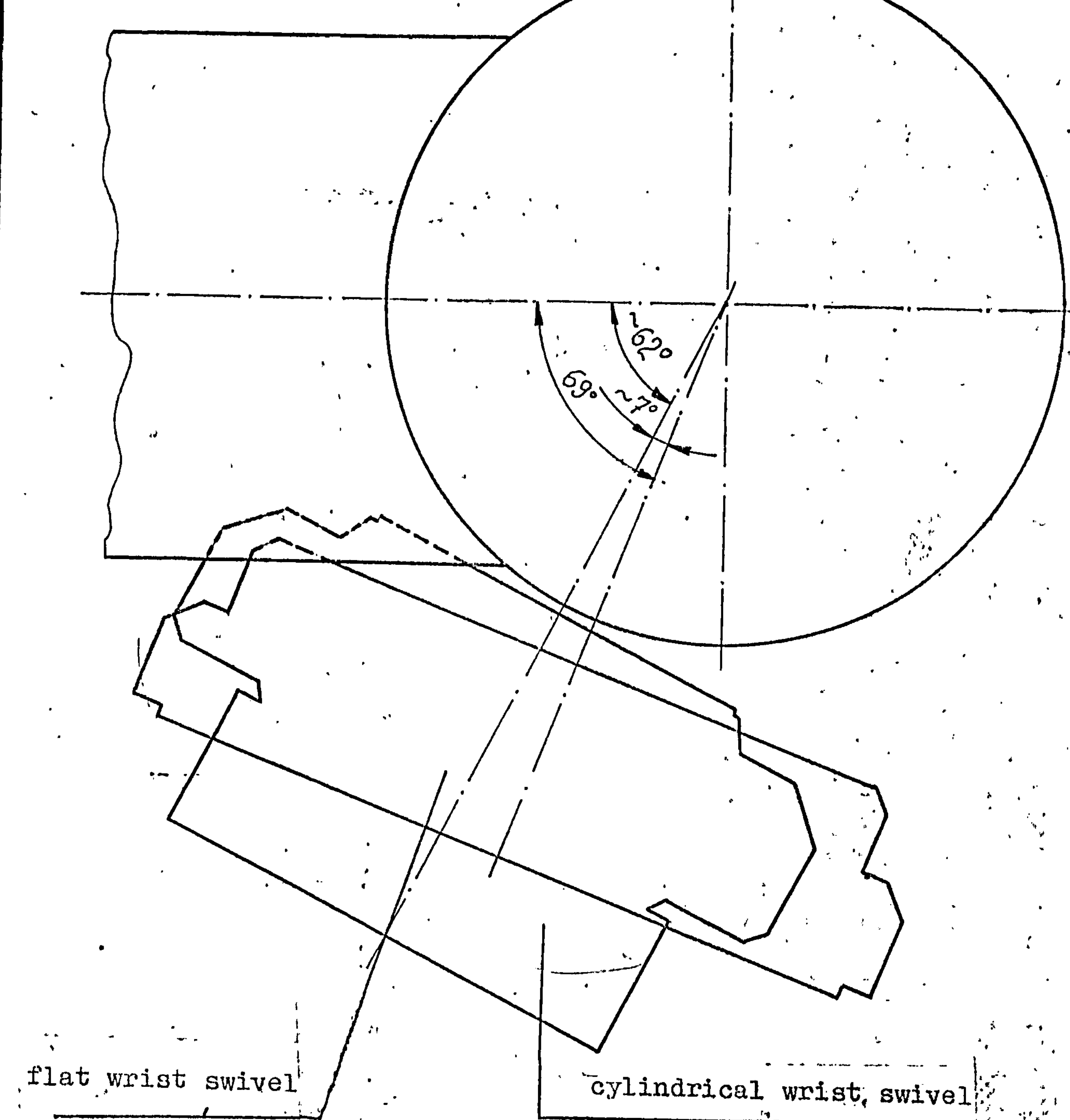
positions 1 - 6 acc. to the tech.spec. of IRb 60

Nr części lub zesp.	Ilość	Nazwa	Nr ark.	Uwagi
		The working range of IRb 60 for casting cleaning		Podziałka 1:10
				Ciężar

Znak zmiany	Ilość zmian	Treść zmiany	Podpis	Data

Projektował			
Konstruował		Z. Rudnicki	V.81r.
Kreślił			
Sprawdził			
Kier. Prac.			
Kier. Zakładu			

Materiał	Zastępuje rys. Nr	Nr ark.
-/-	Zastąpiono przez rys. Nr	Nr rys. zes
Przemysłowy Instytut Automatyki i Pomiarów Warszawa	fig. 3	Nr części 24
Zakład OAK-7		

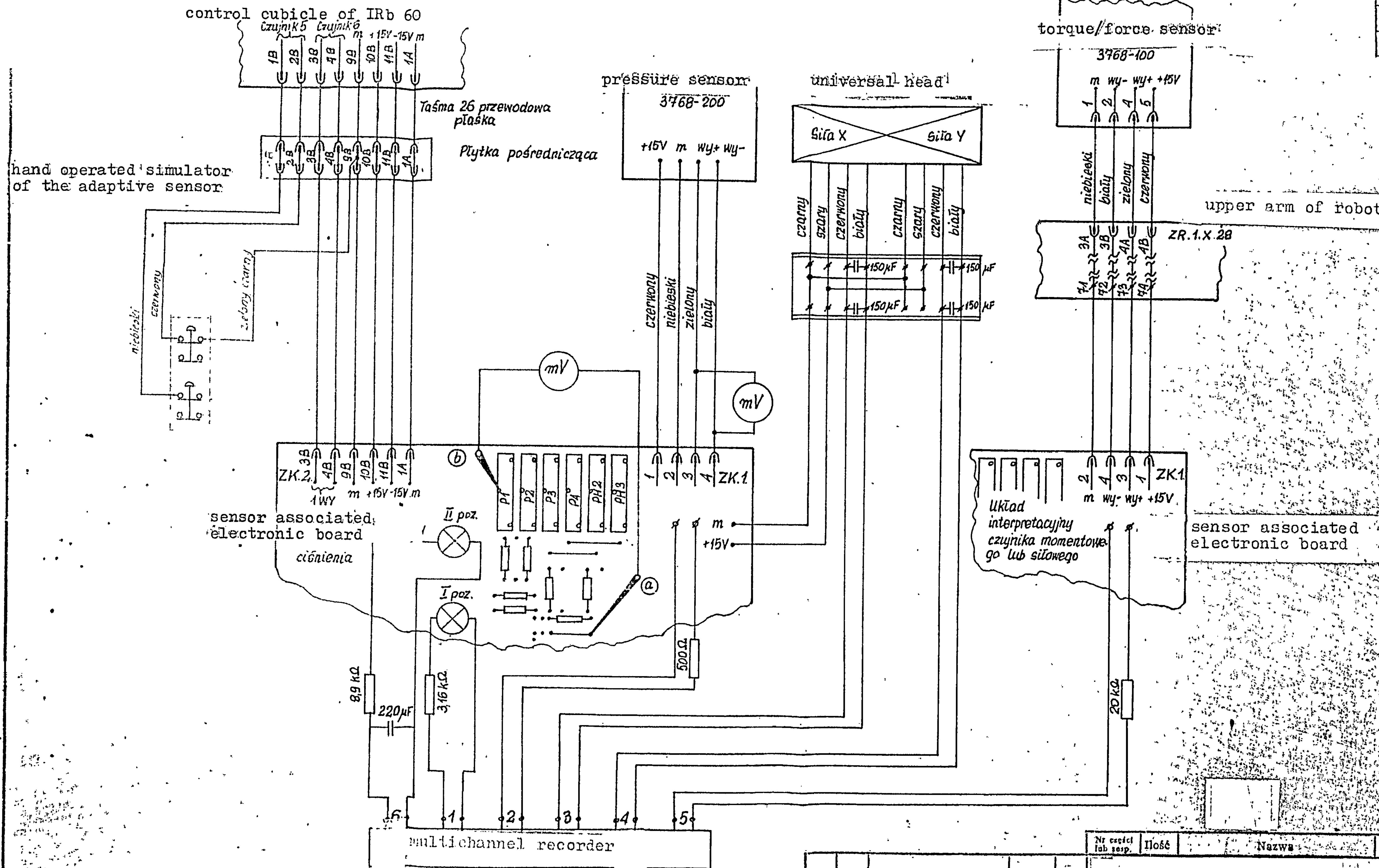


Nr części lub zesp.	Ilość	Nazwa	Nr ark.	Uwagi
		The vertical bending movement t limitation generated by the wrist swivel		

Znak zmiany	Ilość zmian	Treść zmiany	Podpis	Data

Projektował			
Konstruował		Z. Rodnicki	V.81
Kreślił			
Sprawdził			
Kier. Pracowni			
Kier. Zakładu			

Materiał: /	Zastępuje rys. Nr	Nr ark.
	Zastąpiono przez rys. Nr	Nr rys. zest.
Przemysłowy Instytut Automatyki i Pomiarów Warszawa	fig. 4	Nr części 25
Zakład OAK 7		



Nr części lub zesp.	Ilość	Nazwa	Nr ark.	Uwagi

Znak zmiany	Ilość zmian	Treść zmiany	Podpis	Data
Projektował				
Konstruował				
Kreślił				
Sprawdził				
Kier. Prac.				
Kier. Zakładu				

The testing system for adaptive sensors

Materiał

Zastępuje rys. Nr

Zastąpiono przez rys. Nr

Podziałka

Ciężar

Nr ark.

Nr rys. zest.

Nr części

Przemysłowy Instytut Automatyki i Pomiarów Warszawa

fig. 5

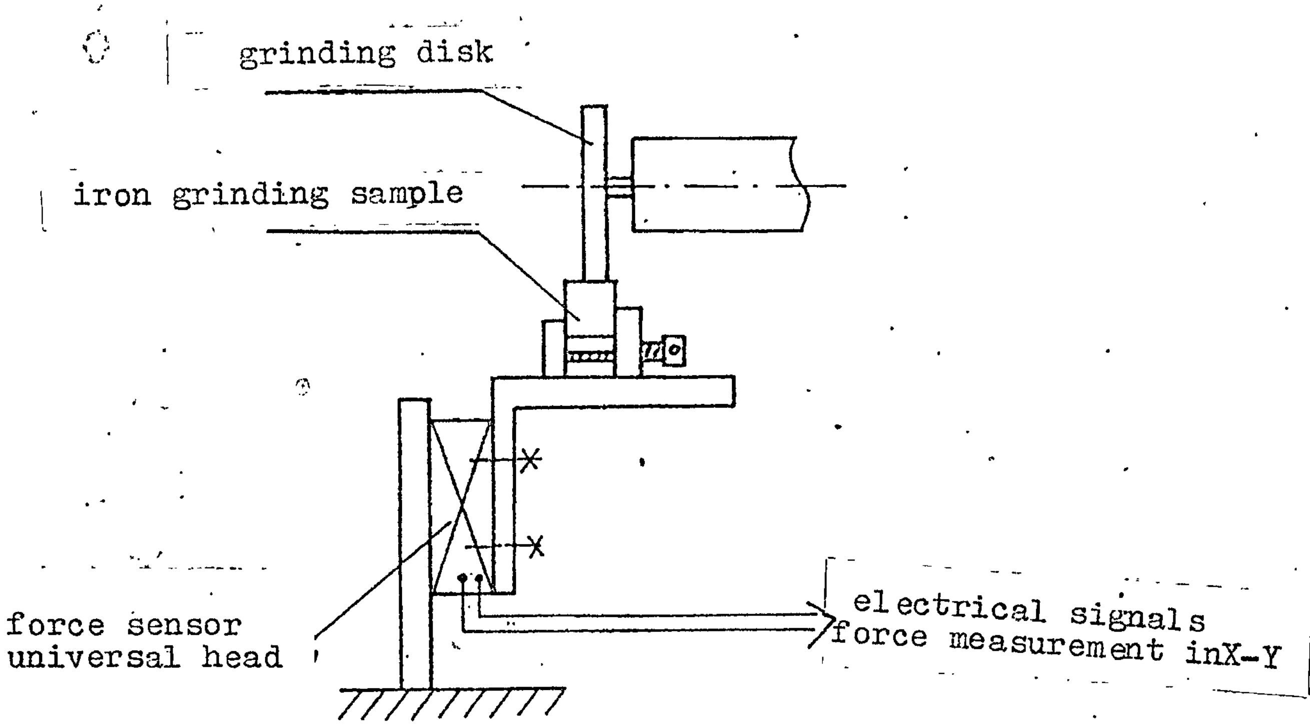


Fig. 6. The universal head with the fixture of the grinding samples.

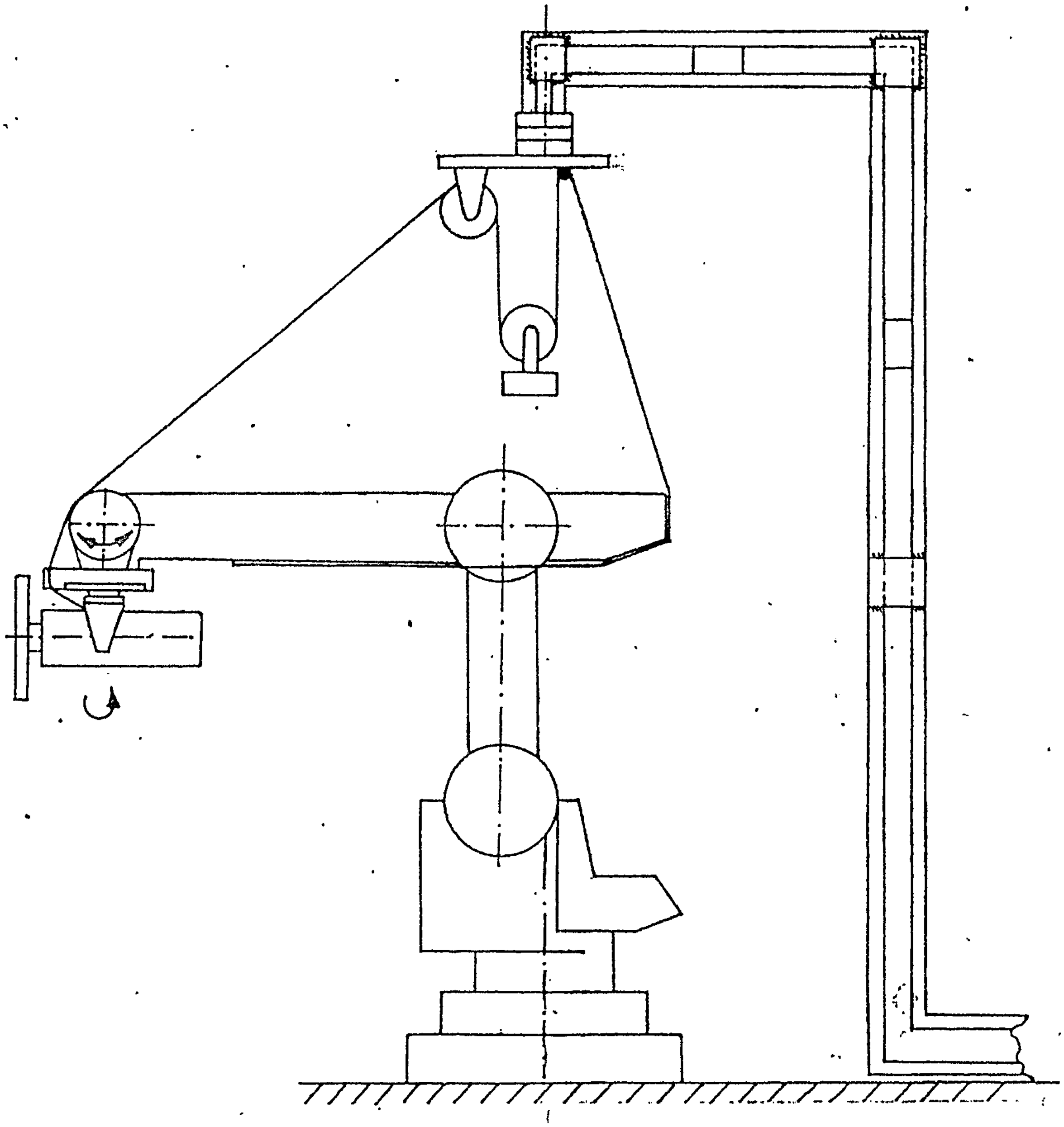


Fig. 7. The cablage between the sensor on the grinding head and robot

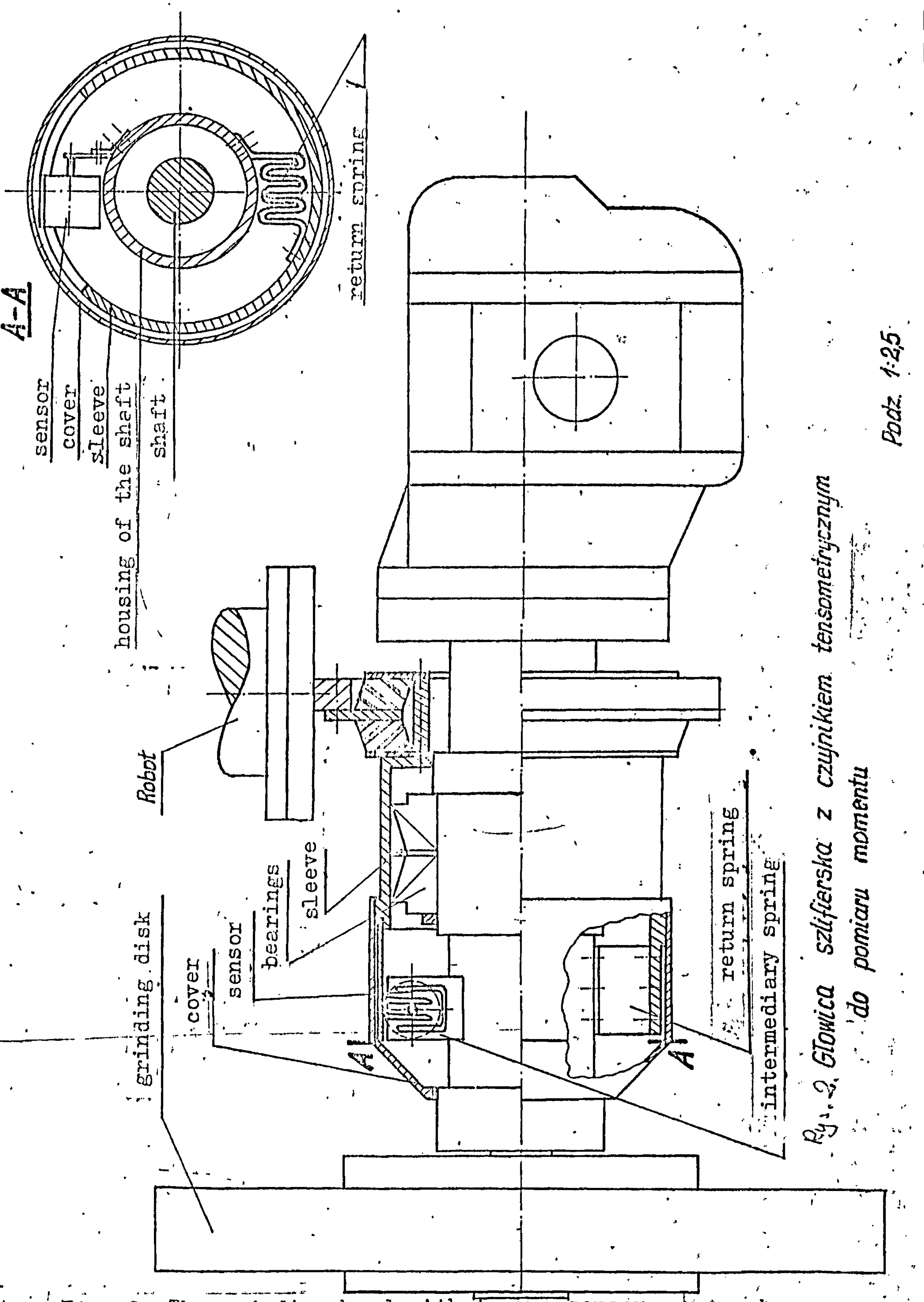


Fig. 8. The grinding head with torque sensor.
scale 1 : 2,5

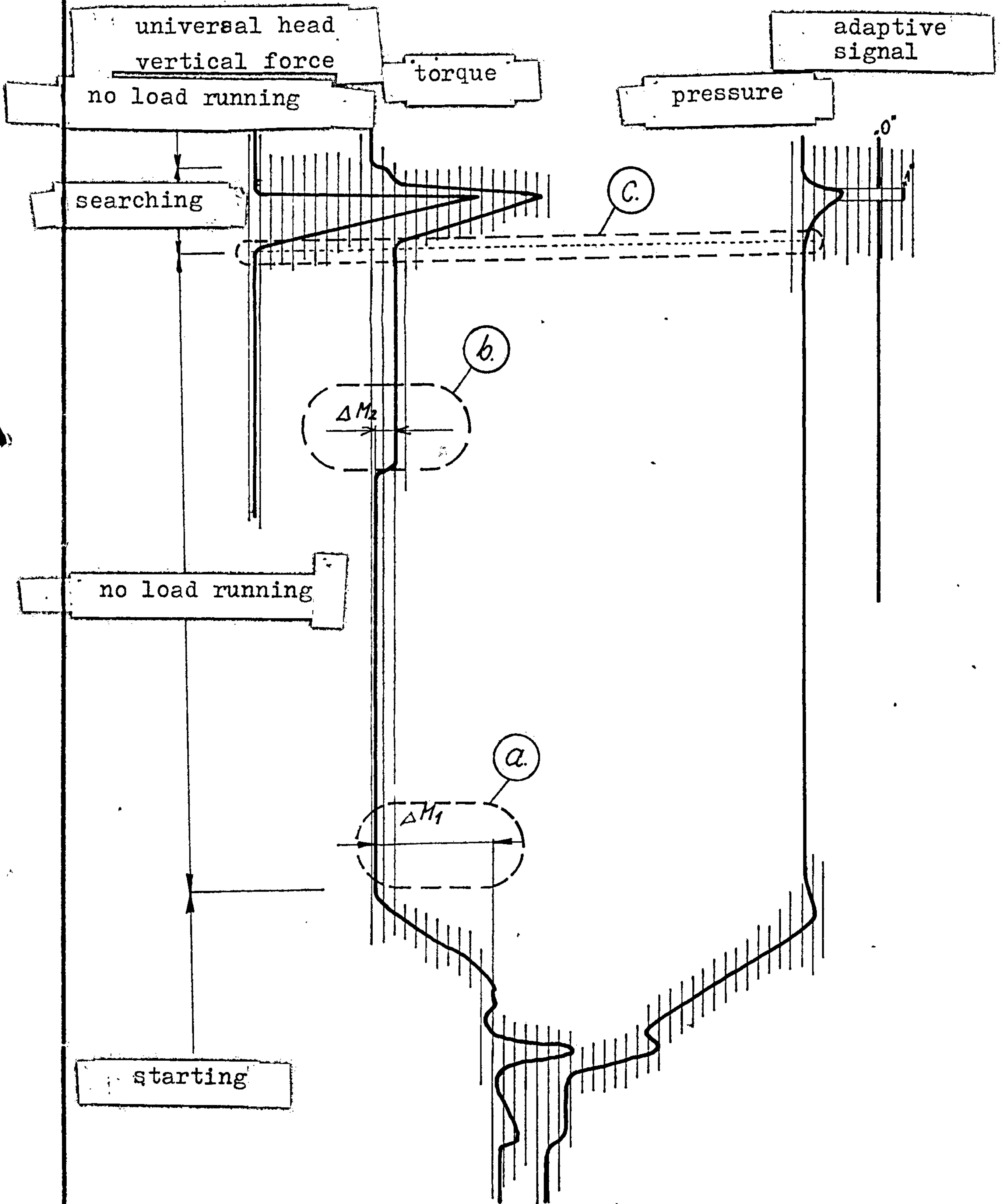


Fig. 9. The torque and pressure signals.
The grinding head without correction of the pipe connections.

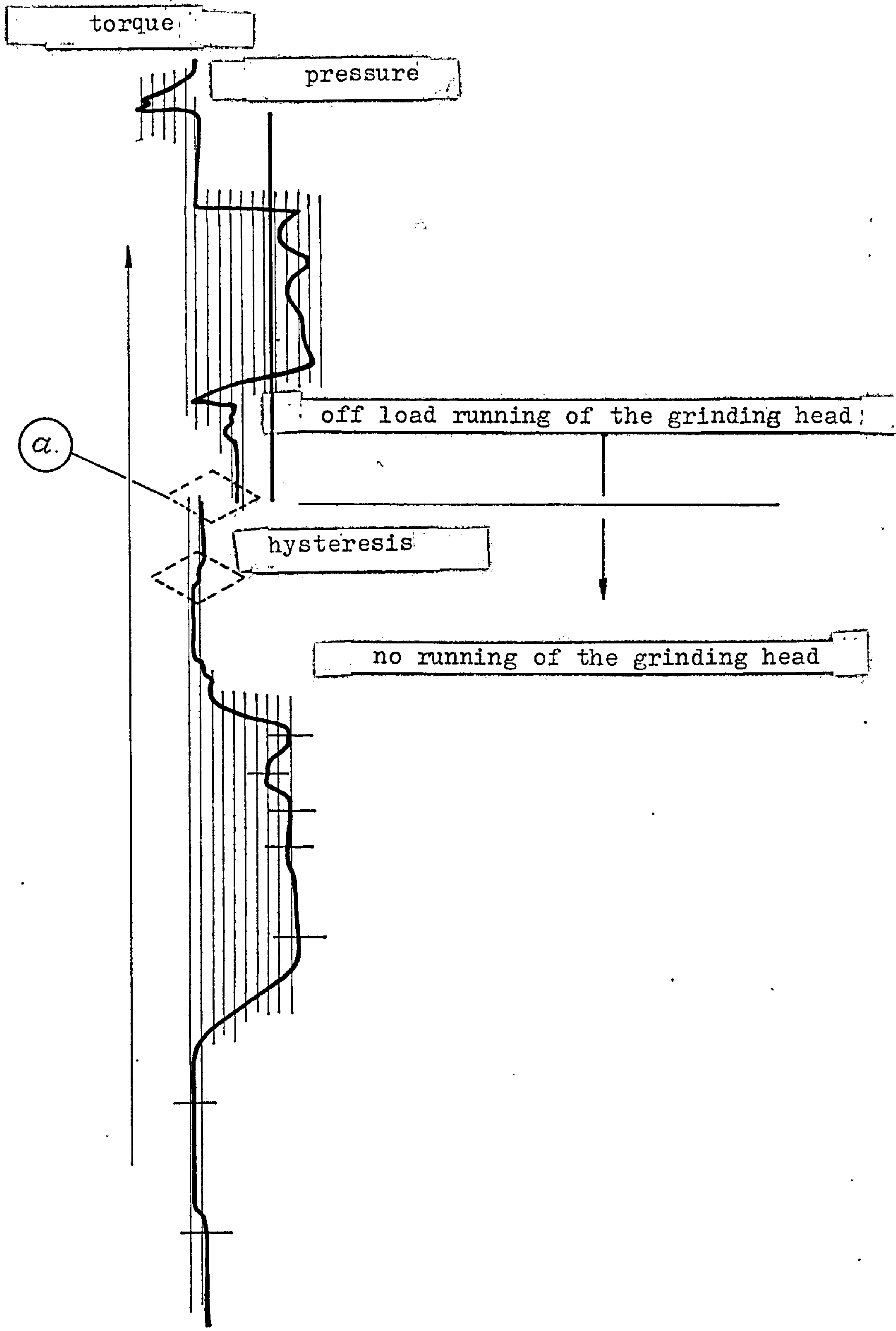


Fig. 10.Dependence of the torque signal on the positions of the the grinding head and the axles of the robot.

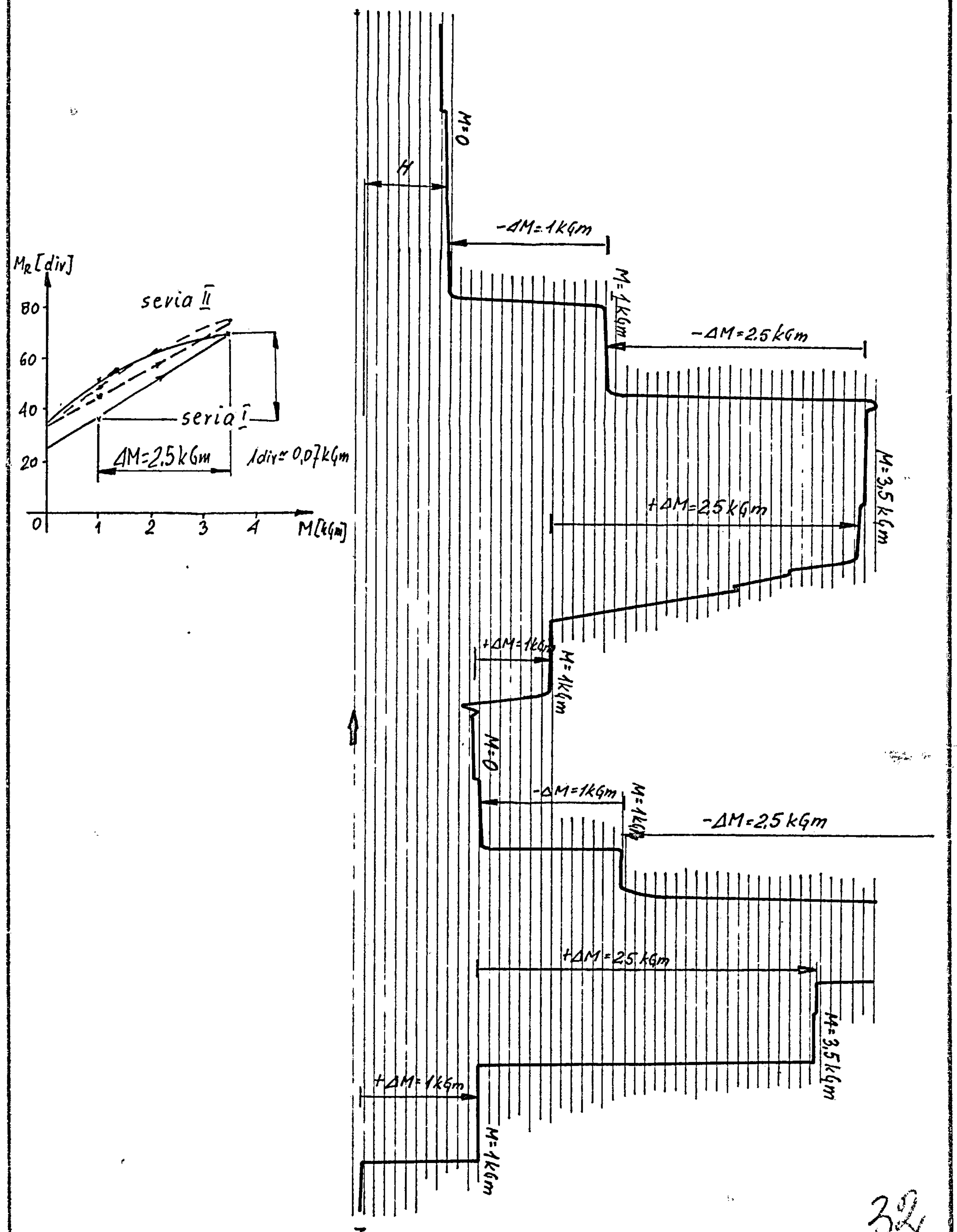


Fig. 11. Scaling of the torque signal

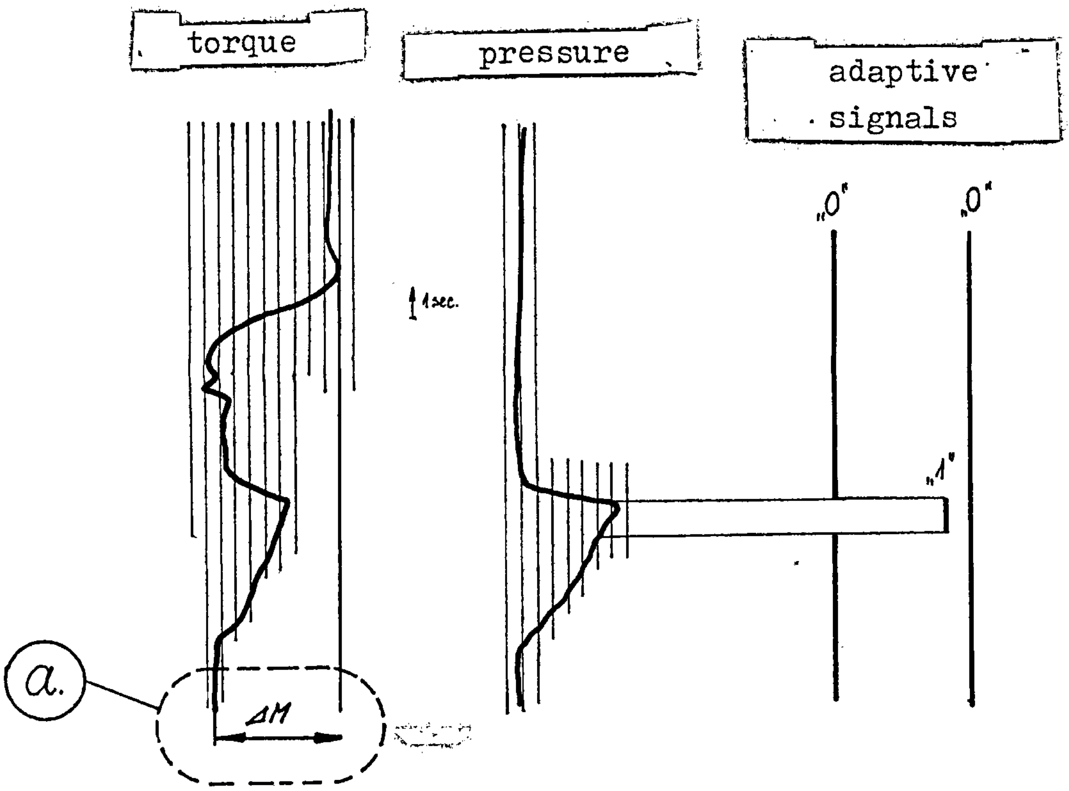


Fig. 12. The torque and pressure signals when grinding

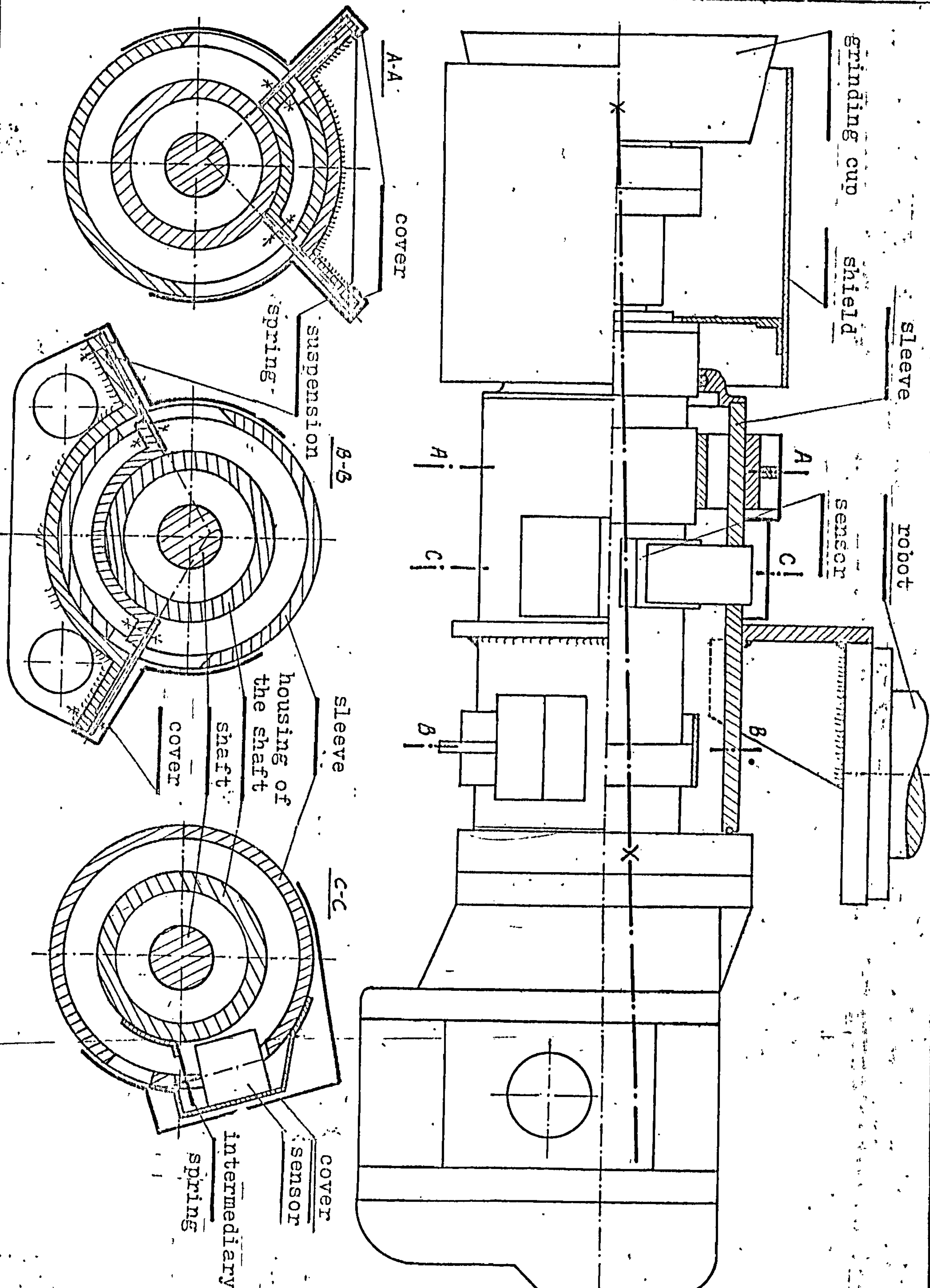


Fig. 13. Grinding head with the torque sensor , version II.
Scale 1 : 2,5

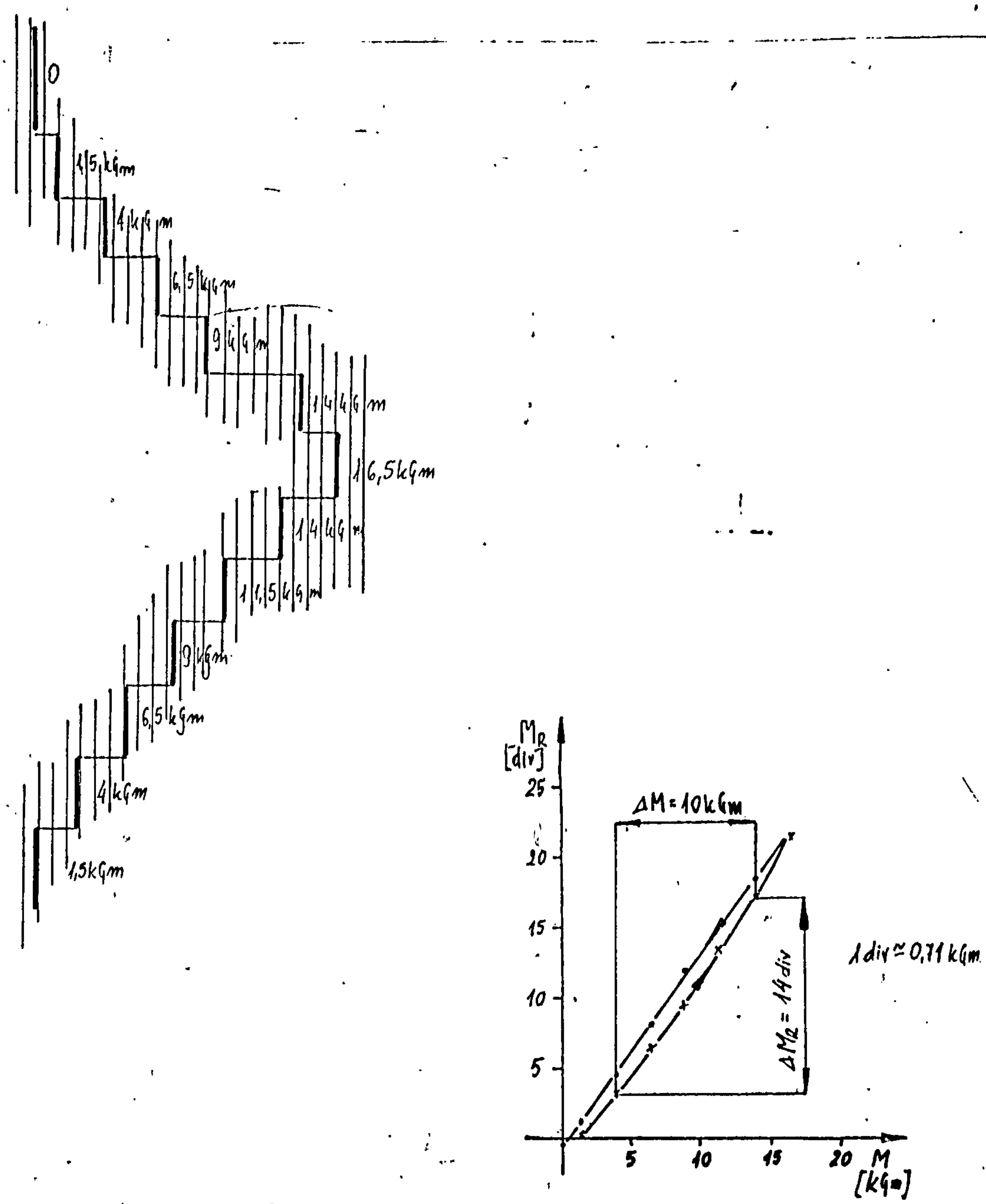


Fig. 14. Scaling the torque signal , version II.
Stiff intermediary spring .

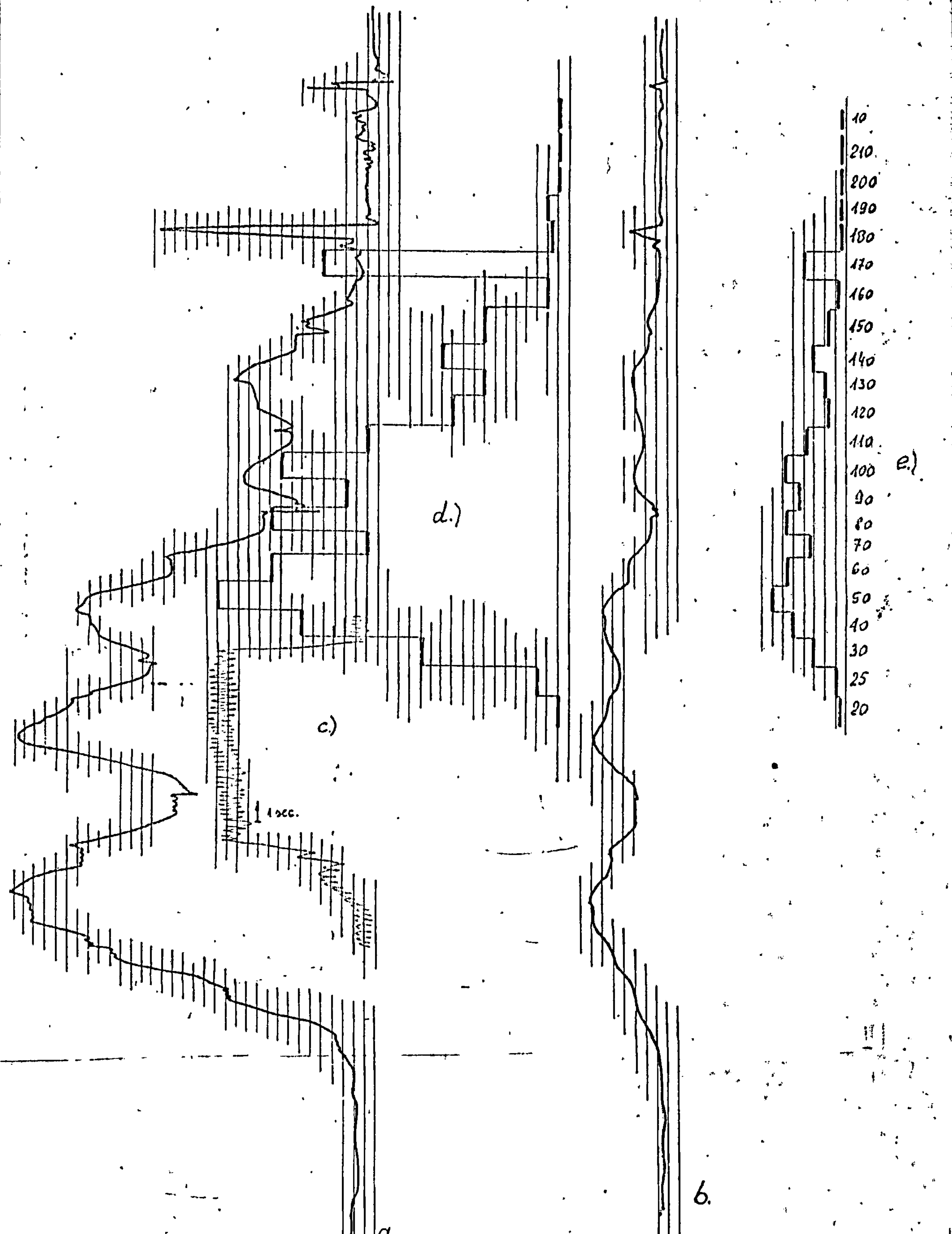


Fig. 15. Torque signals , version II.The dependence of the signal on the positions of the grinding head.
a./,d./ - stiff intermediary spring ; b./,e./- limp intermediary spring; c./- real grinding signal; a./,b./- live signals; c./,e./- signal levels in diff.positions of grinder.

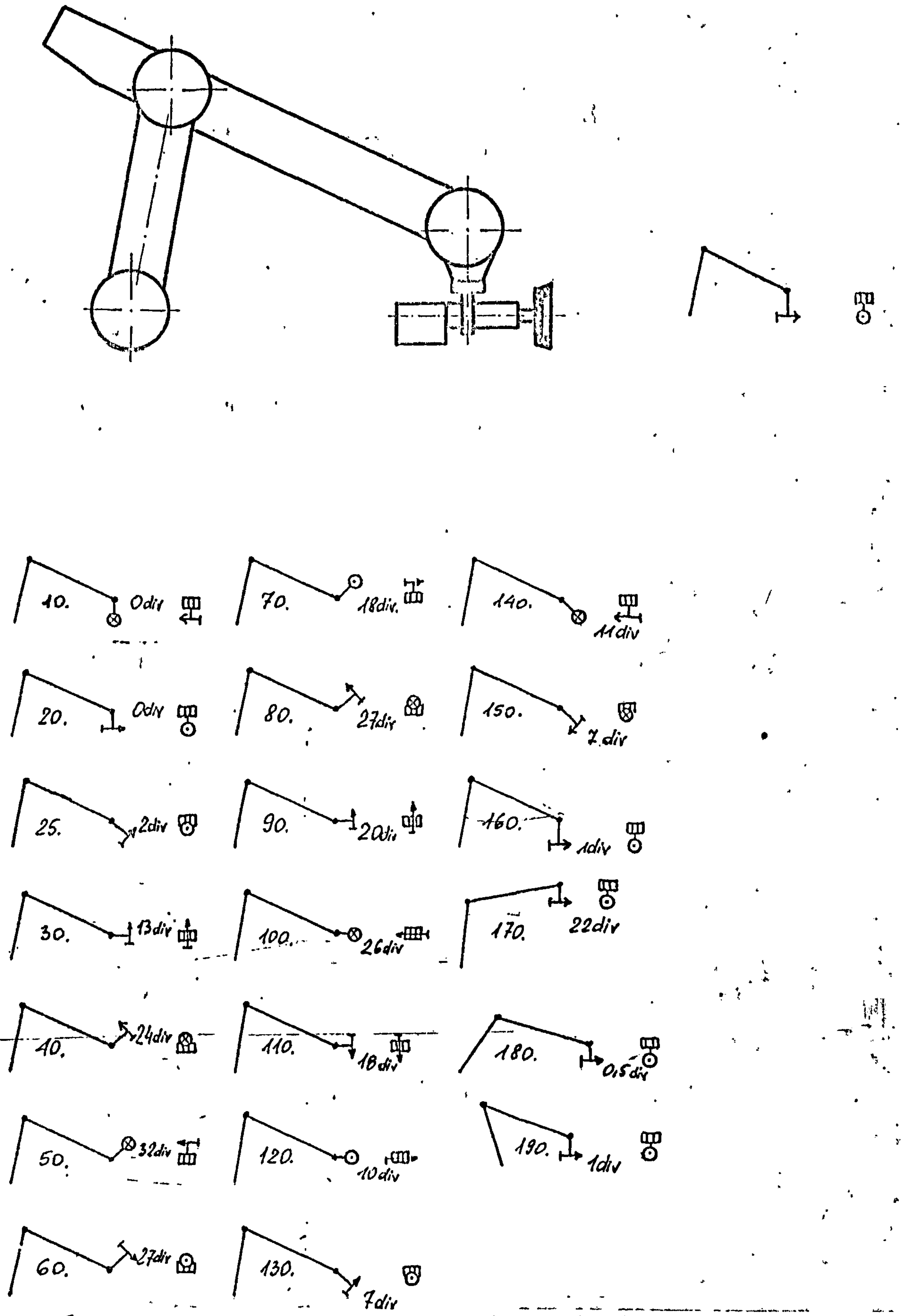


Fig. 16. Positions of the robot and the grinding head.
Deviations of the torque signal in /div/ /from the graph/.

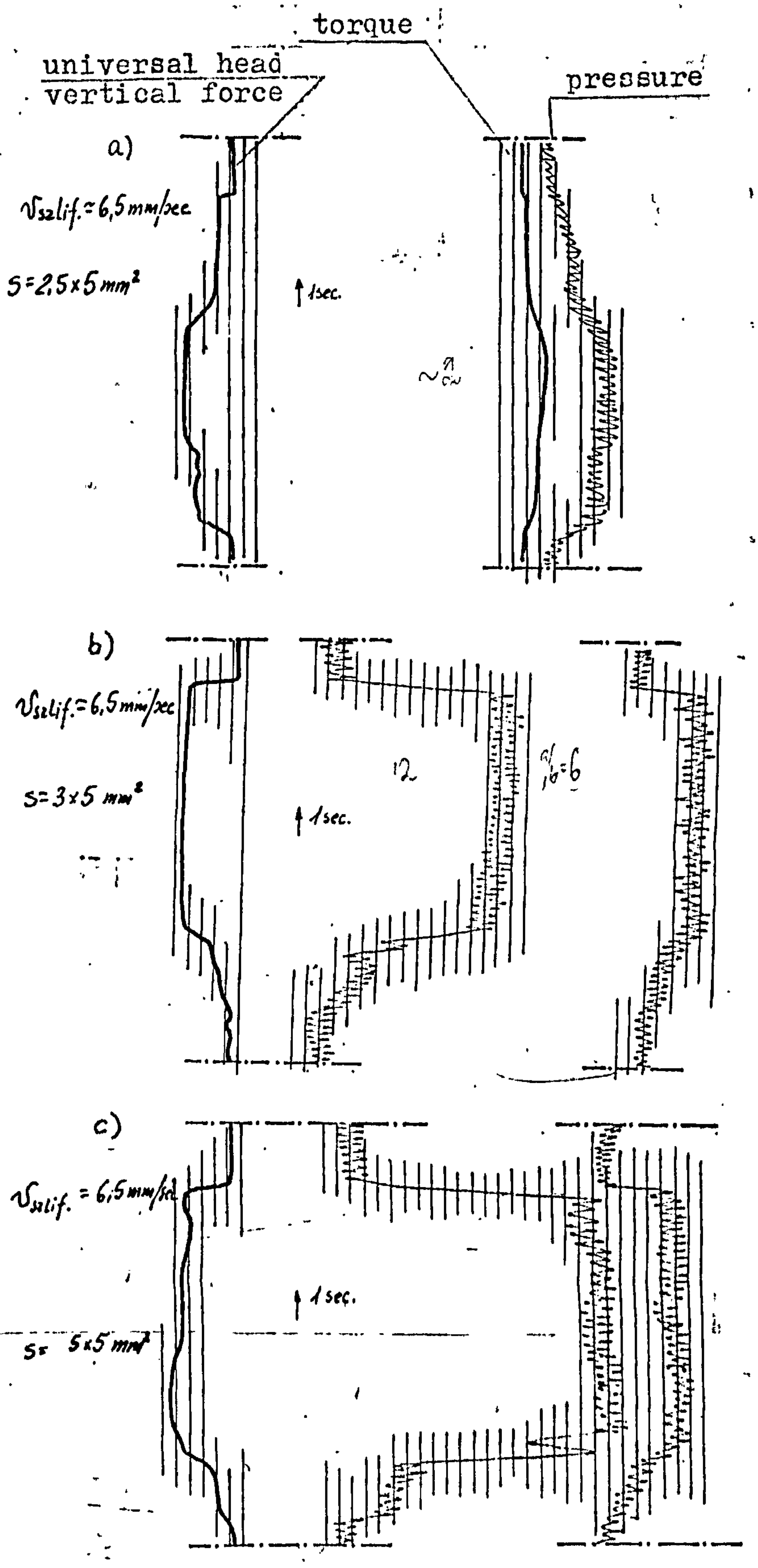


Fig. 17. The real grinding signals.for diff. loads.
a./-limp intermediary spring ; b./,c./- stiff intermediary spring.

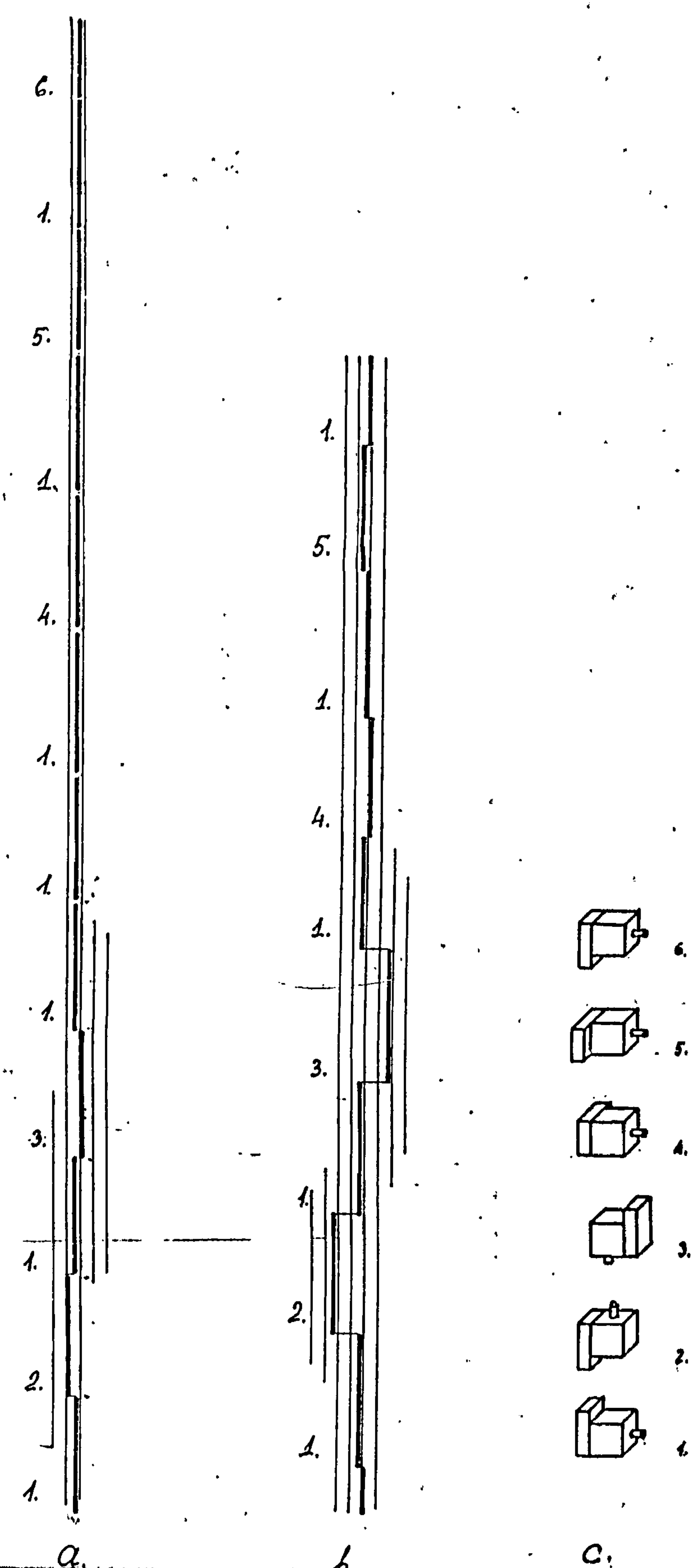


Fig. 18. Dependence of the sensor signal on the position of the sensor; a./- unloaded sensor; b./- 14 G load on the pusher of sensor; c./- positions of the sensor.

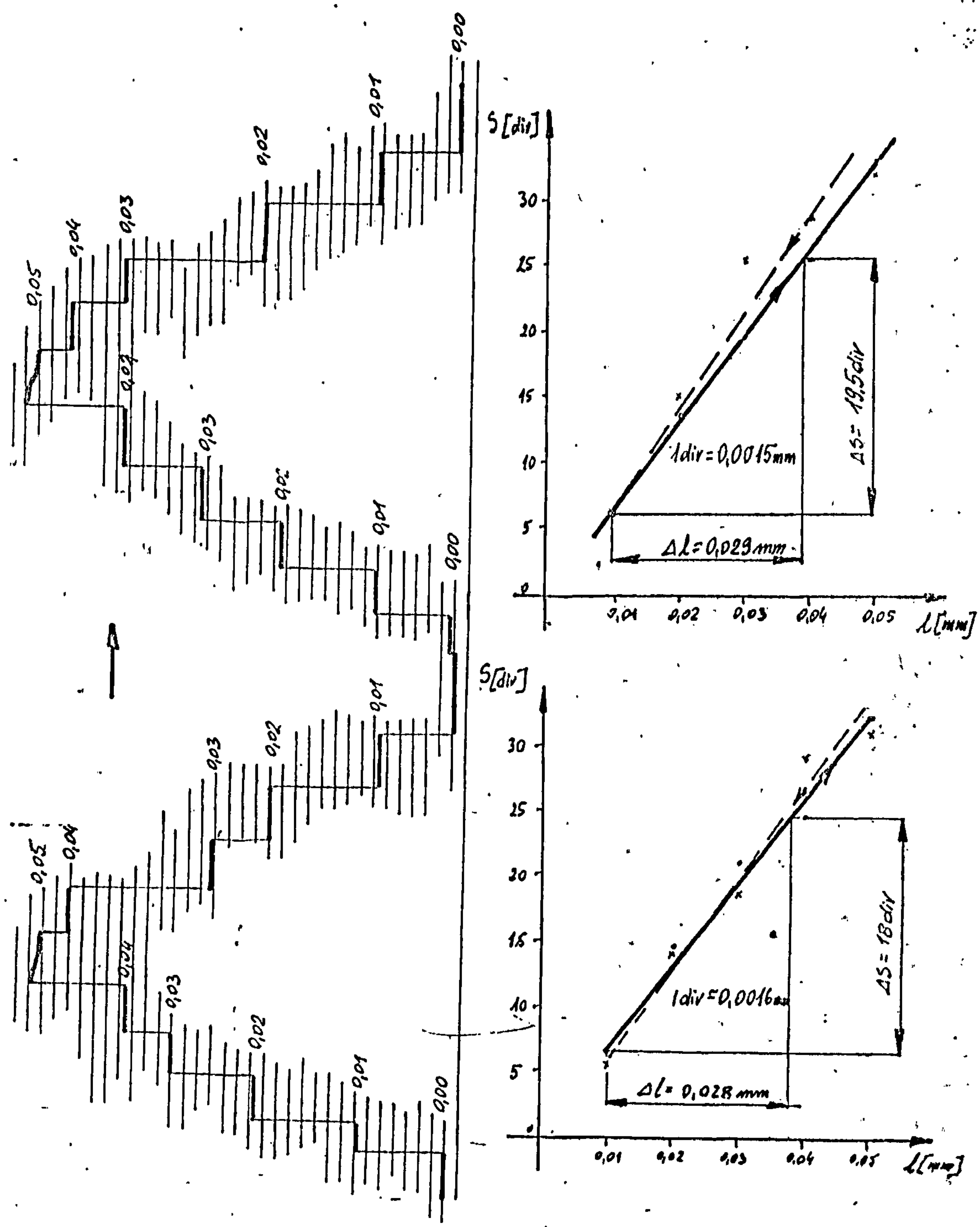


Fig. 19. Graph of dependence of the signal on the coaxial movement of the pusher of the sensor.

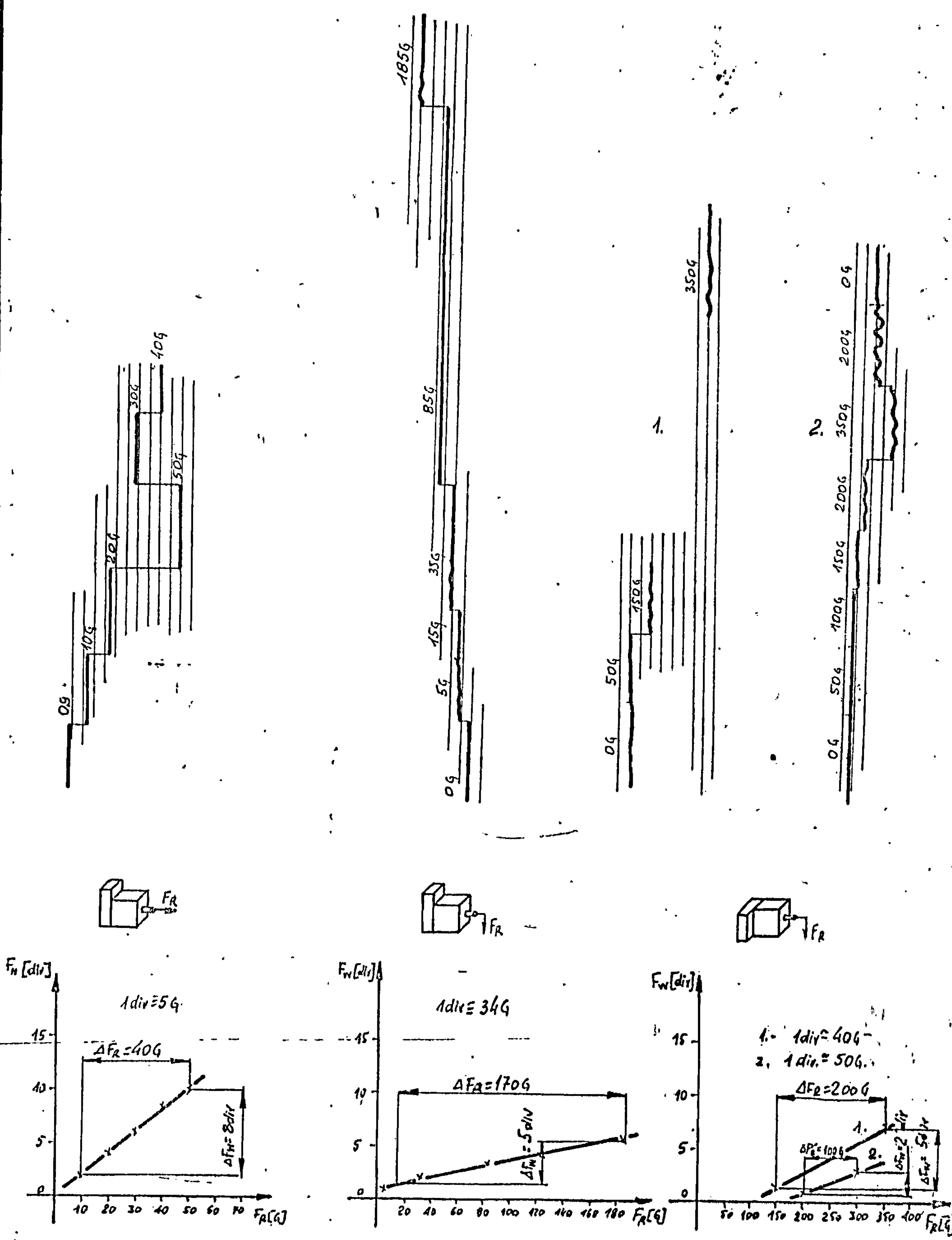


Fig. 20. Graph of dependence of the signal on the load on the pusher of the sensor /in diff. directions/.

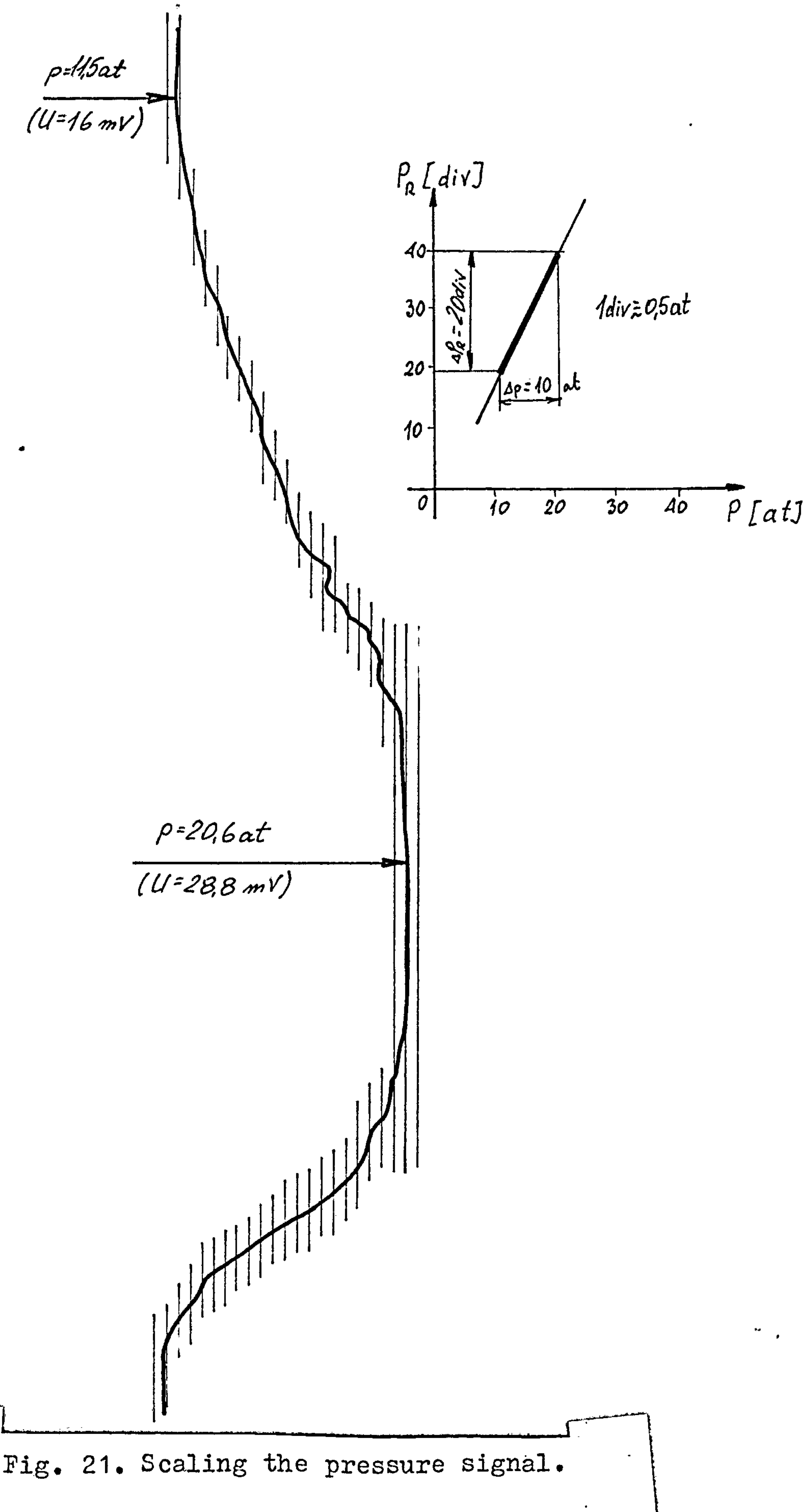


Fig. 21. Scaling the pressure signal.

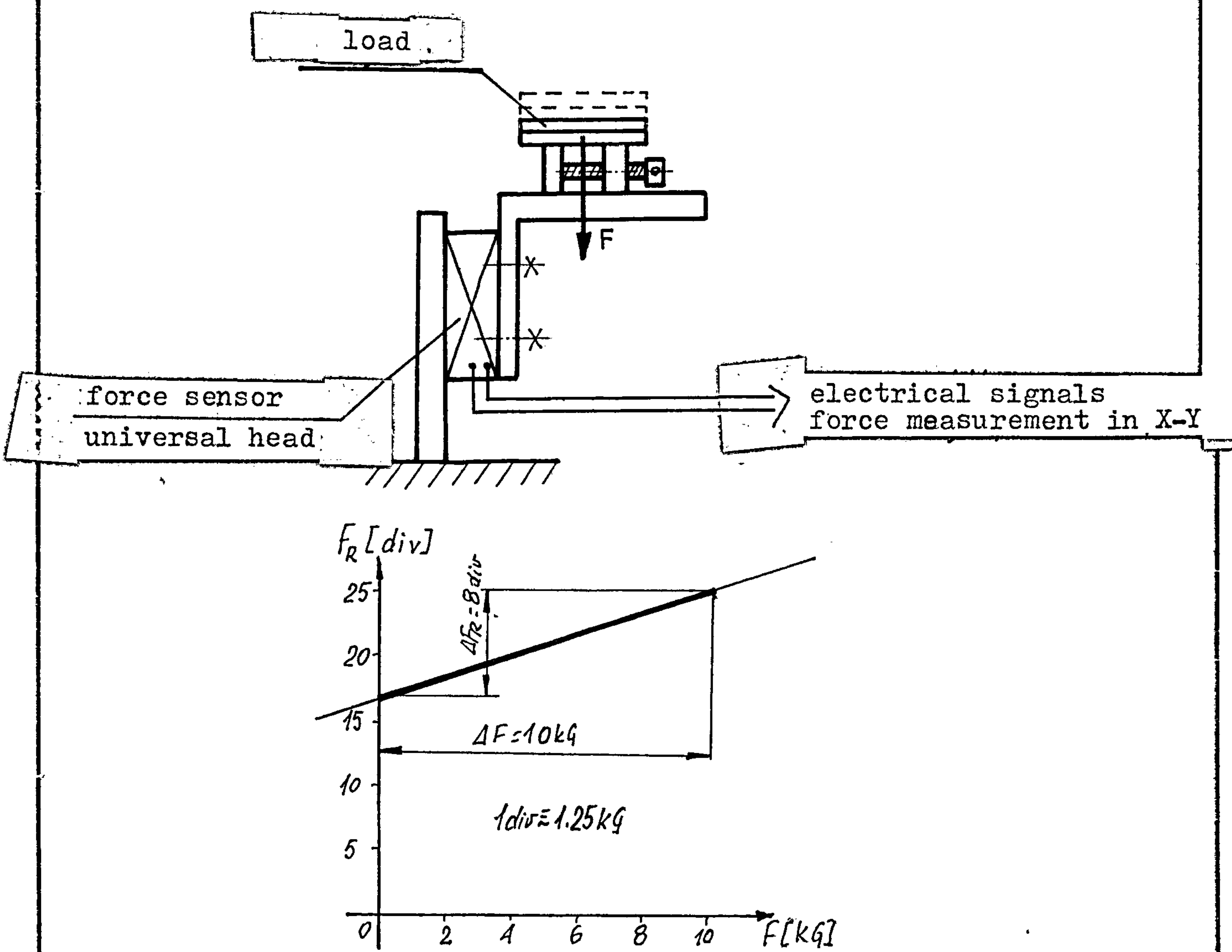


Fig. 22. Scaling the universal head force sensor.

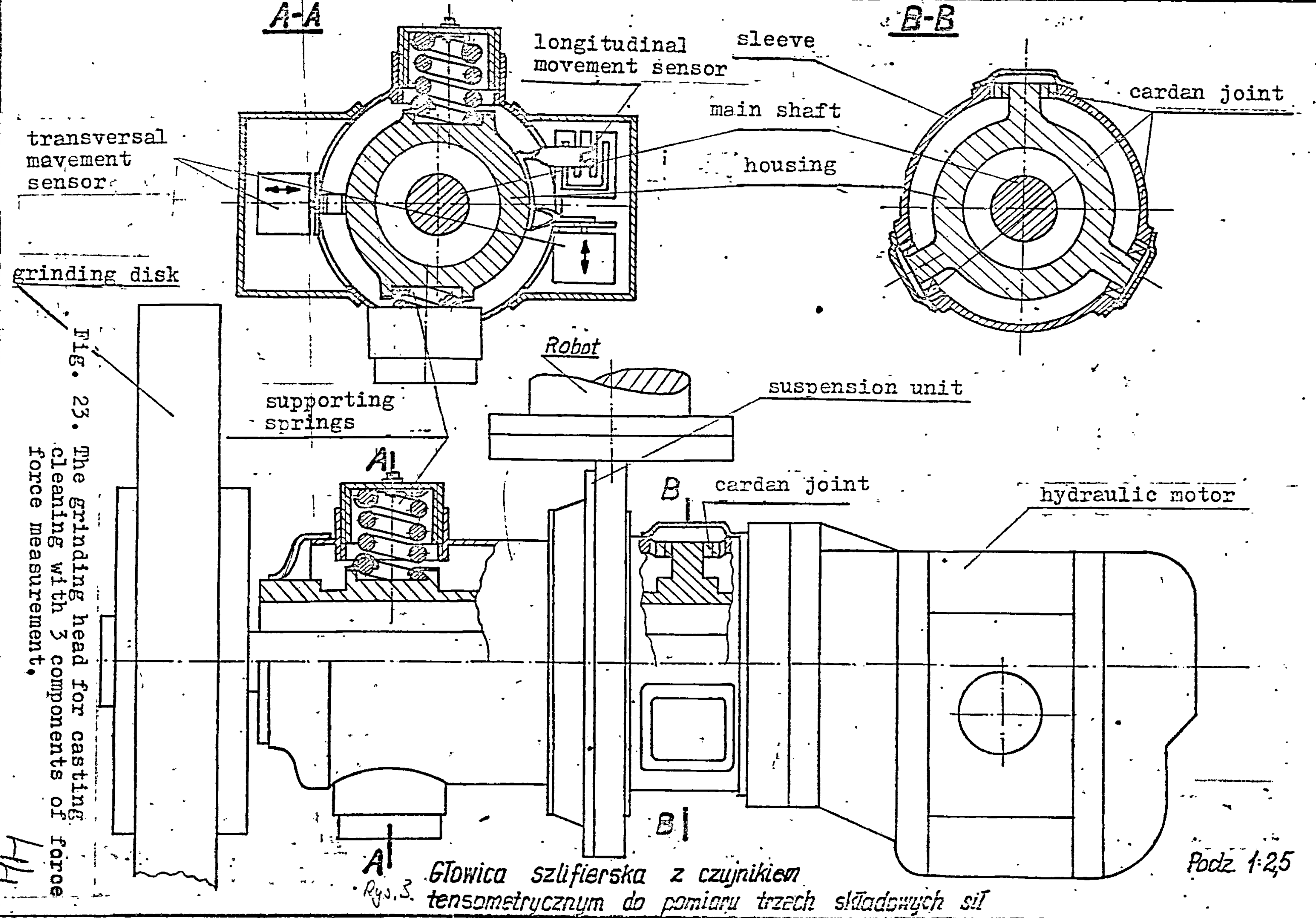


Fig. 23. The grinding head for casting cleaning with 3 components of force force measurement.

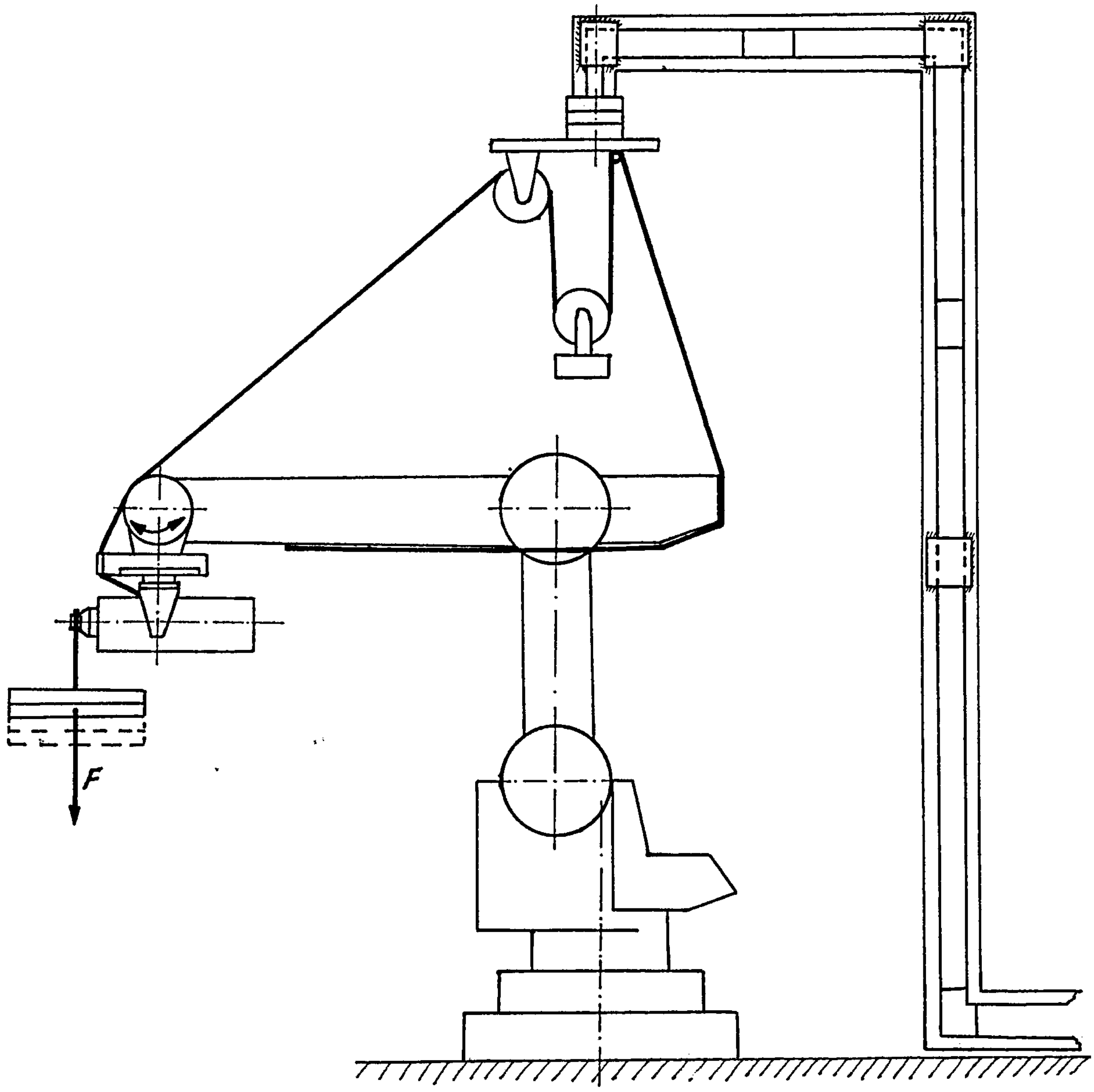


Fig. 24. The calibration of the force grinding head.

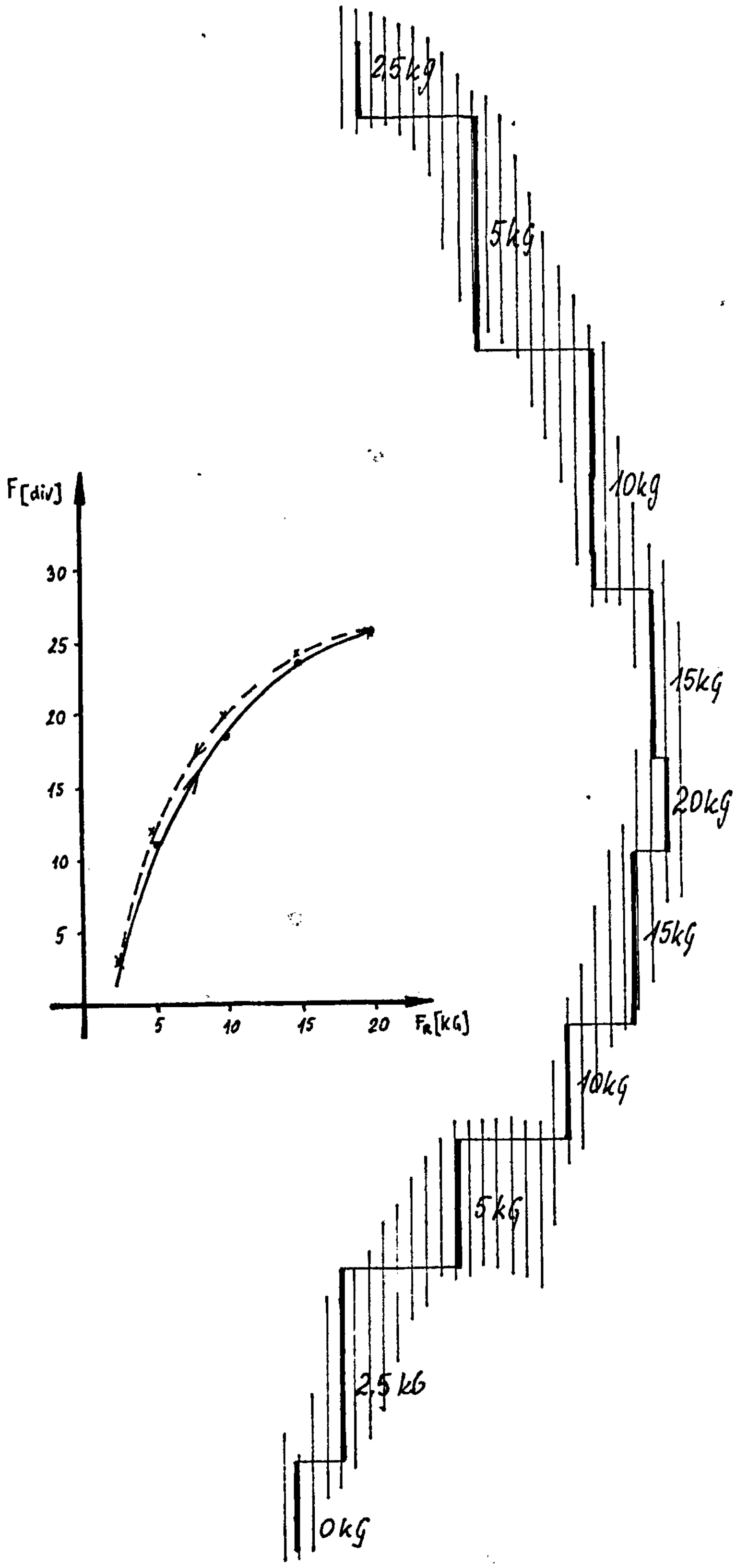
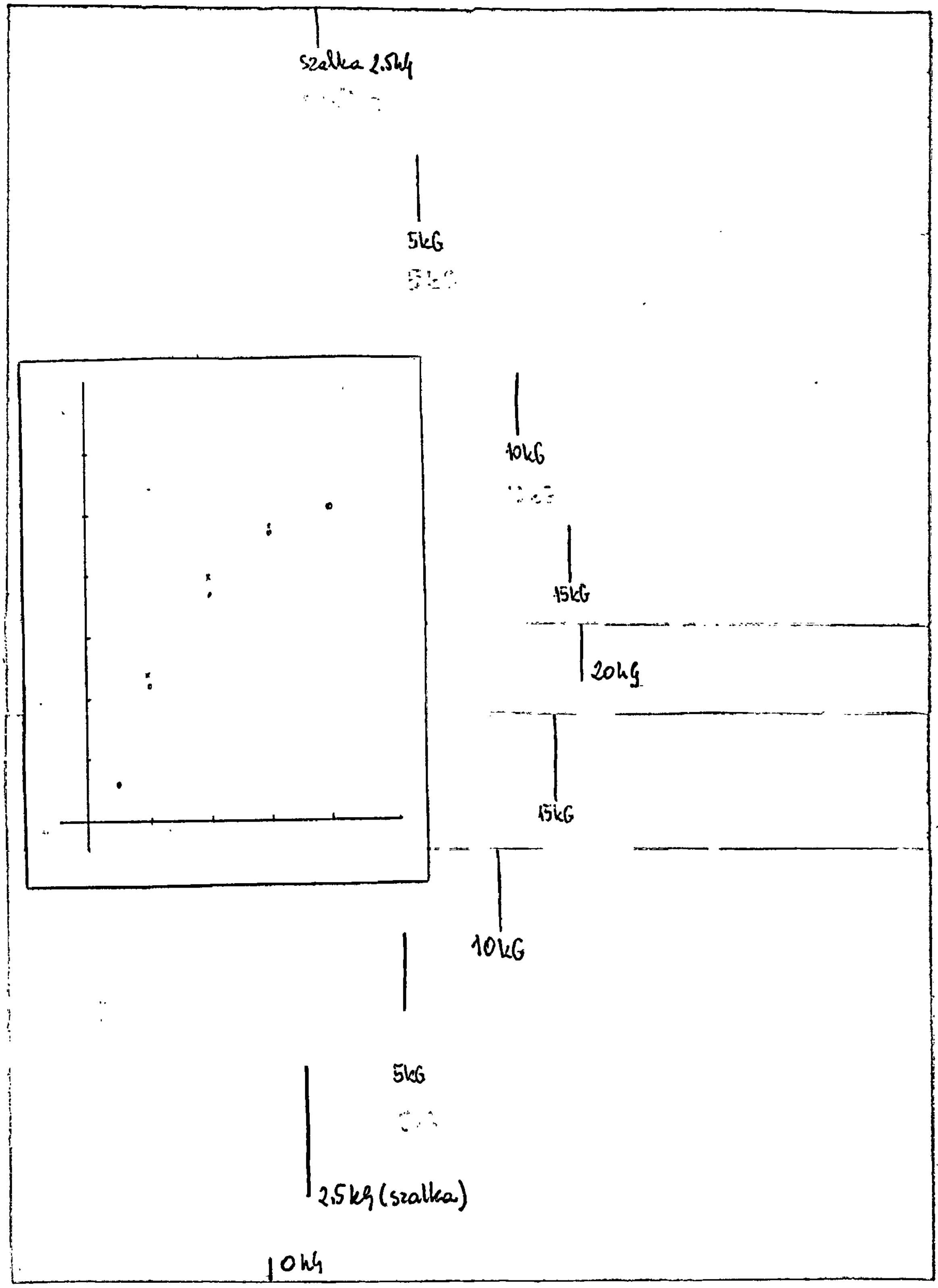
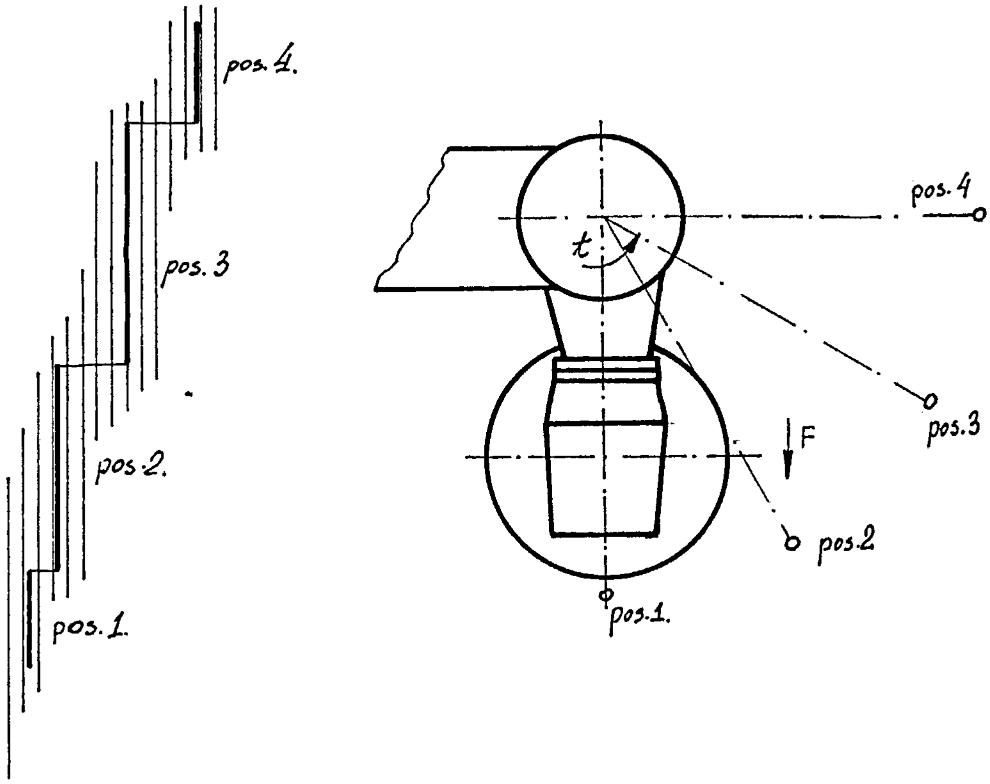


Fig. 25. The grinding head with force sensor; scaling of the vertical force signal.



SKALOWANIE [illegible] fig. 20



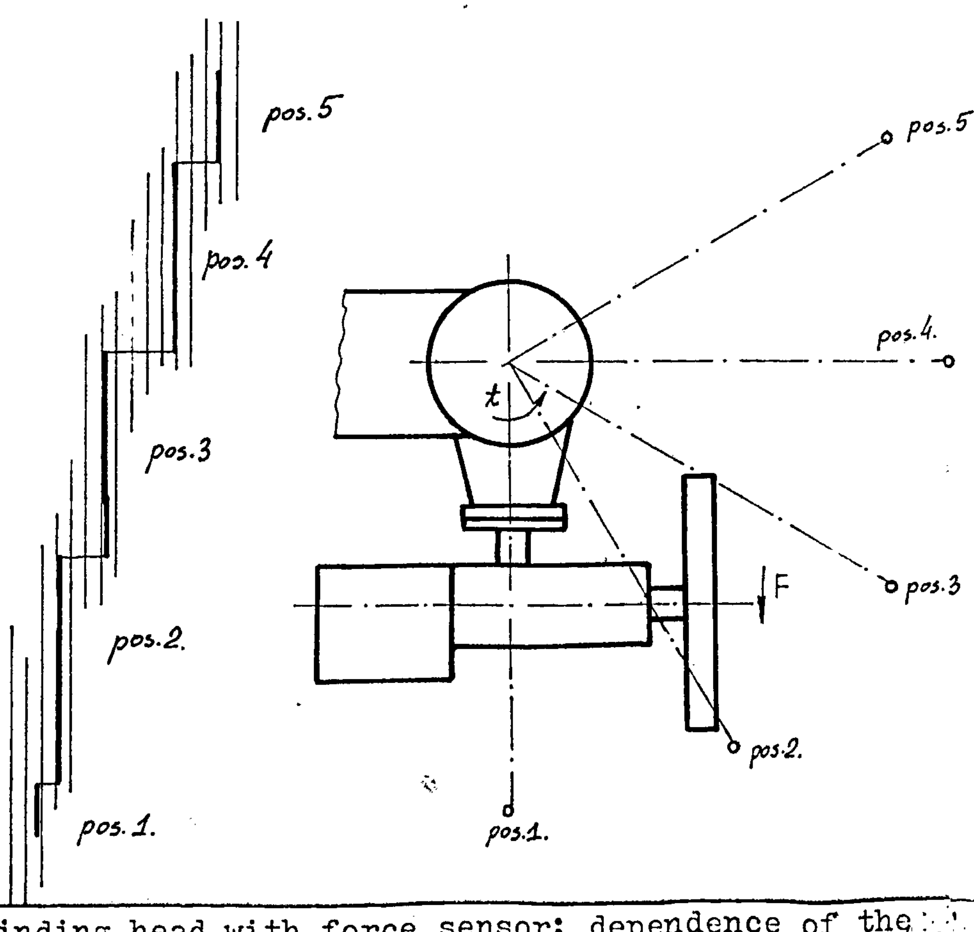
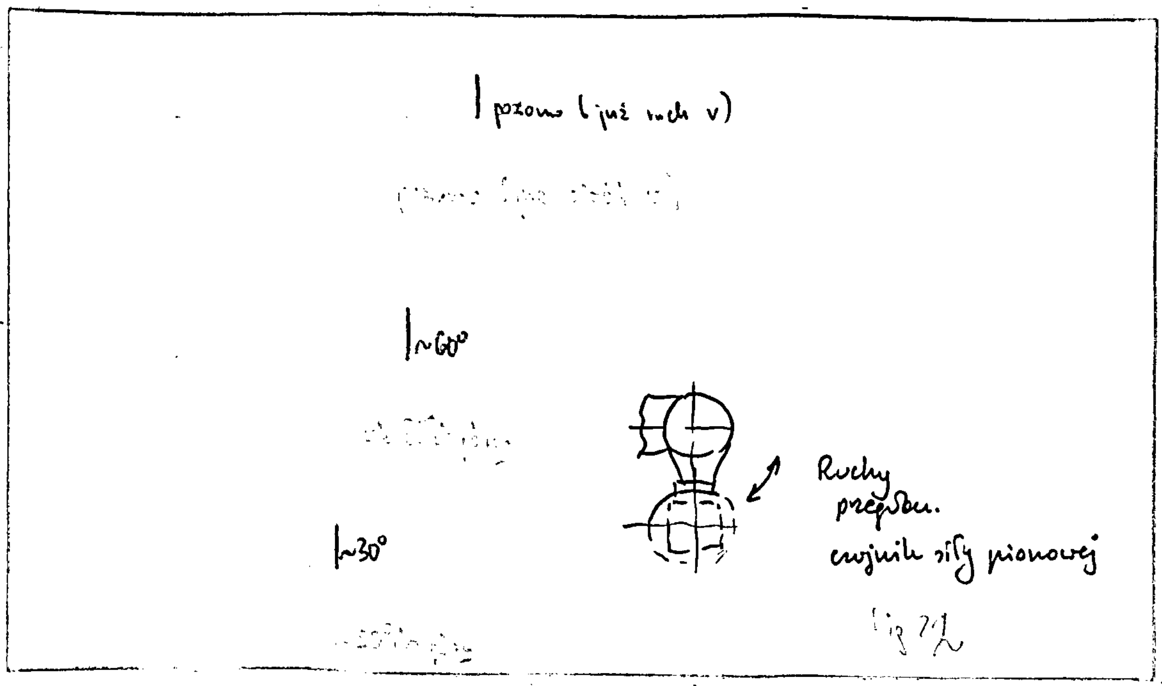


Fig. 26. The grinding head with force sensor; dependence of the force signal on the position t of the wrist.



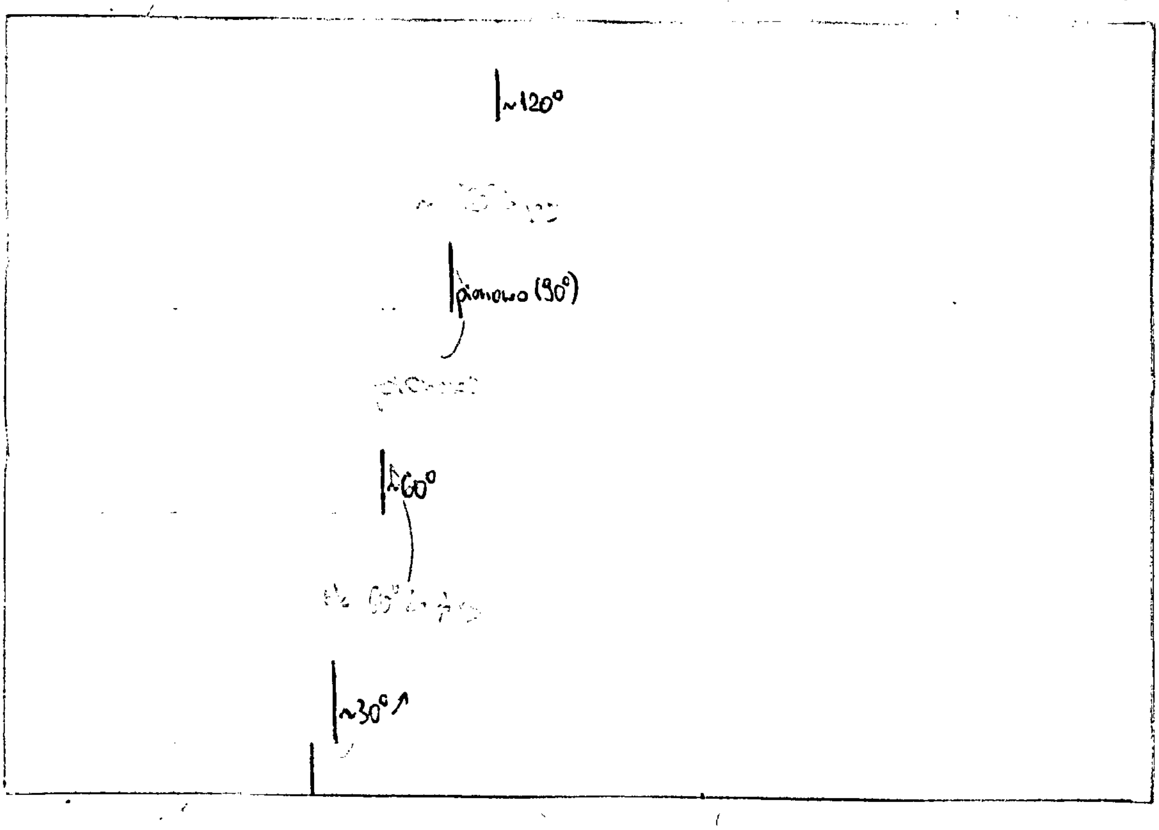


fig 21. Zależność sygnałów od położenia głowicy siłowej dla czujnika siły pionowej; dołu - głowica poziomo, pod rozumieniem ... [illegible]

universal head vertical force

grinding head force signal

pressure

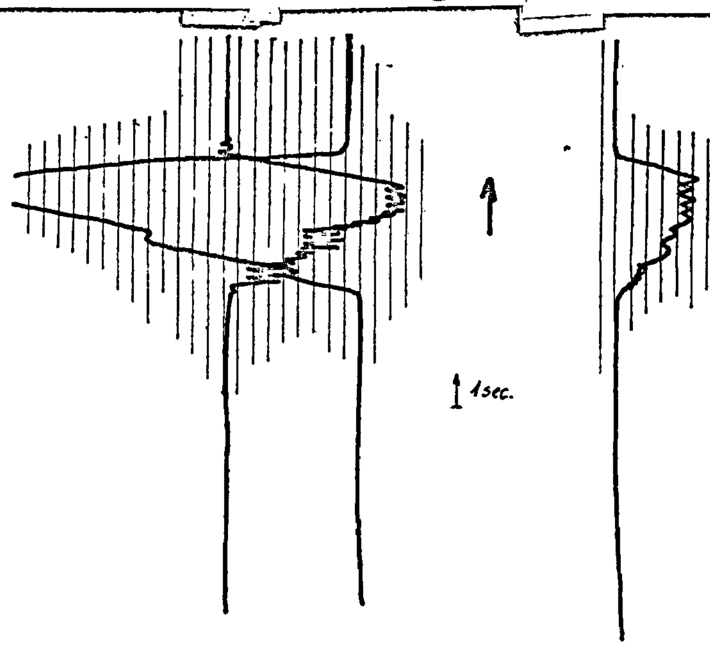
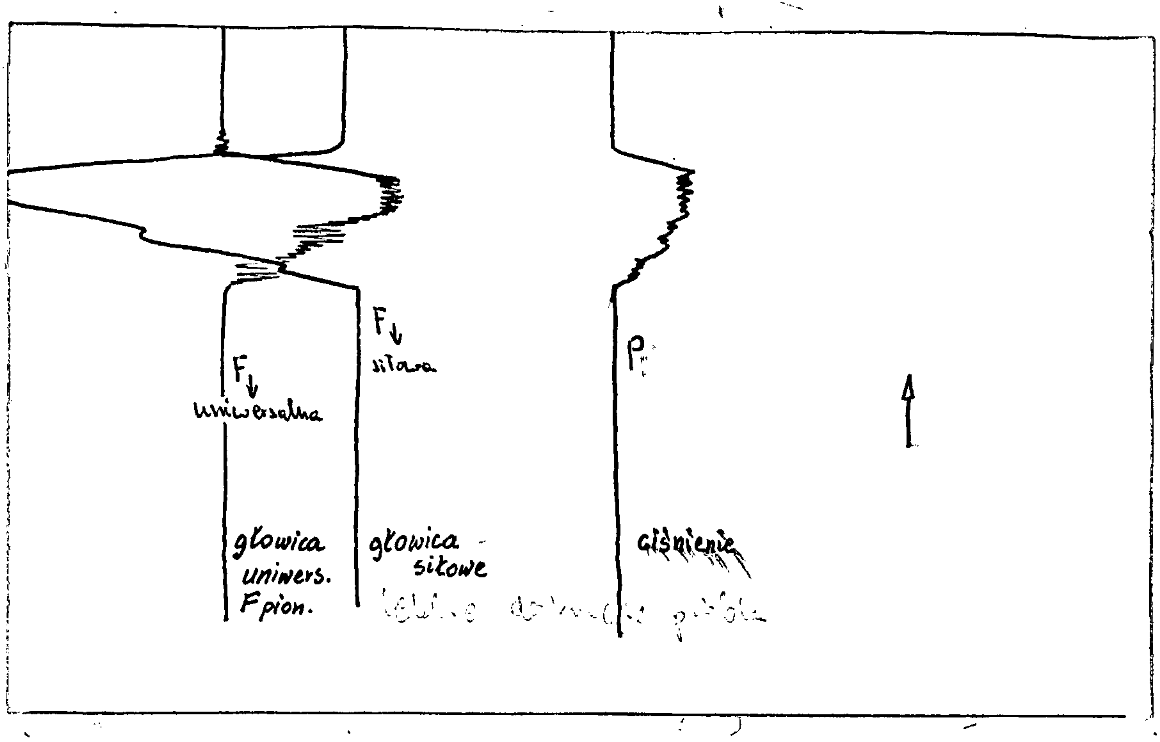


Fig. 27. The grinding head with force sensor.Removal a little volume of iron.

fig. 23. Wykres głowicy siłowej, rejestruje sygnał z czujnika siły pionowej głowicy, [illegible] pionowej głowicy uniwersalnej oraz ciśnienie oleju w instalacji podczas szlifowania. [illegible] [illegible]



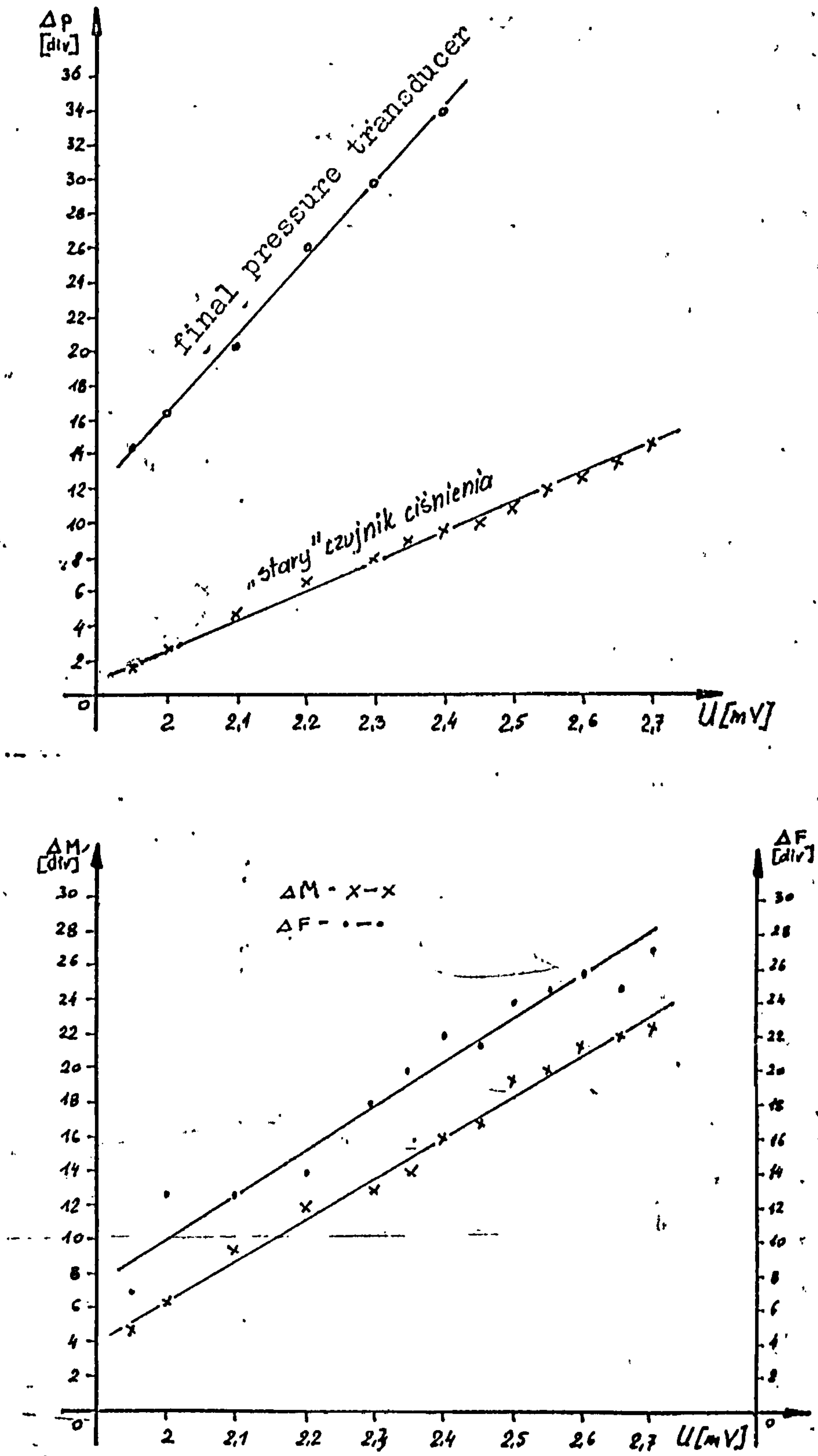
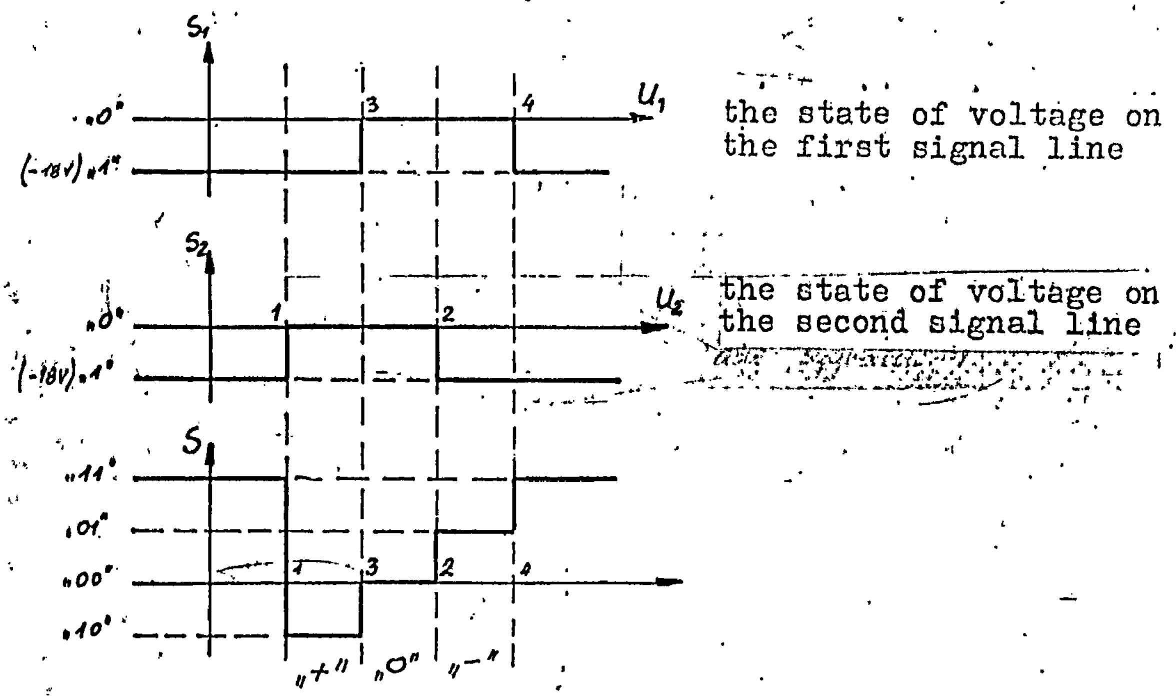


Fig. 28. Pressure p=, torque M , force F /from the universal head/ equivalent of setting of treshold 2.



Formation of the adaptive signal with the numbers of tresholds

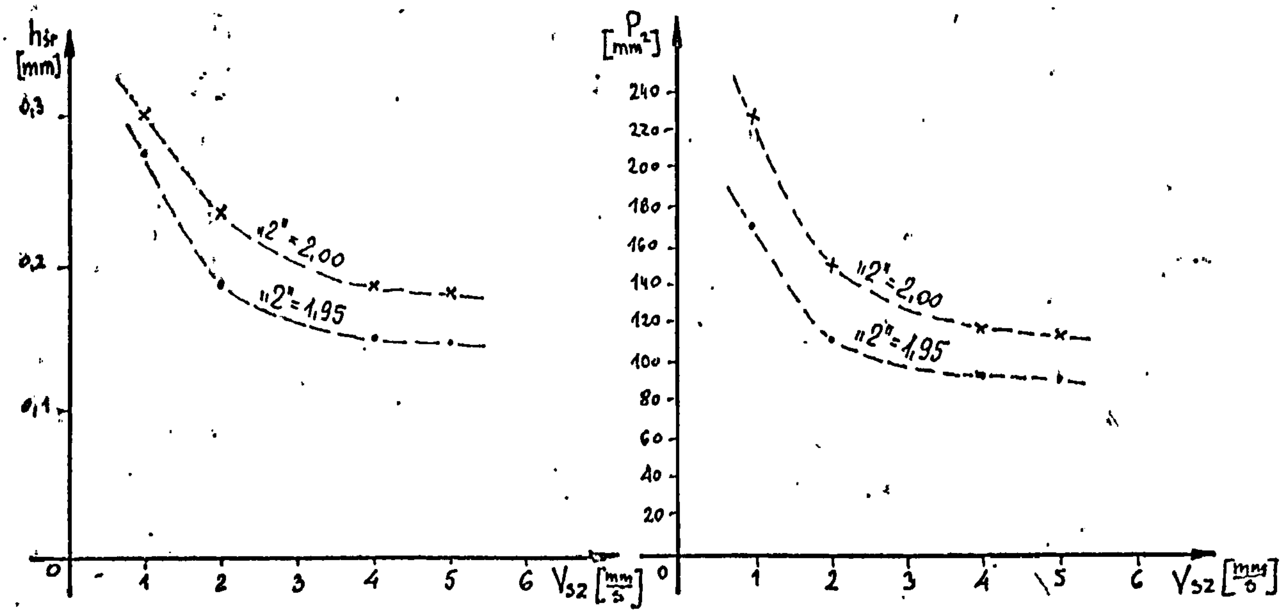


Fig. 29. COARSE SEARCHING : the effect of grinding off the touched surface in function of the treshold 2 setting and the searching speed.

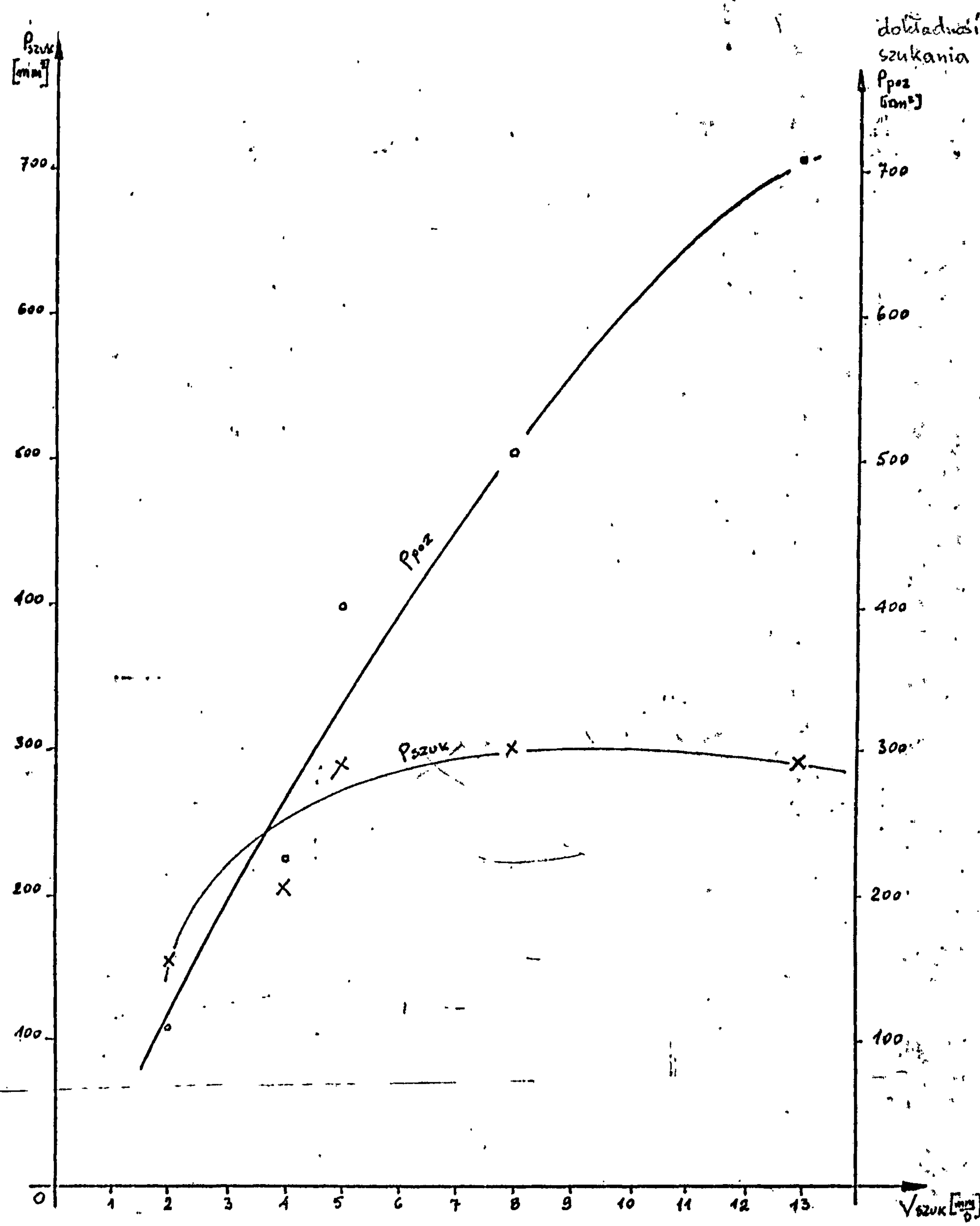


Fig. 30. COARSE SEARCHING : the influence of searchng speed on grinding off the touched surface and on the accuracy of positioning of the tool.

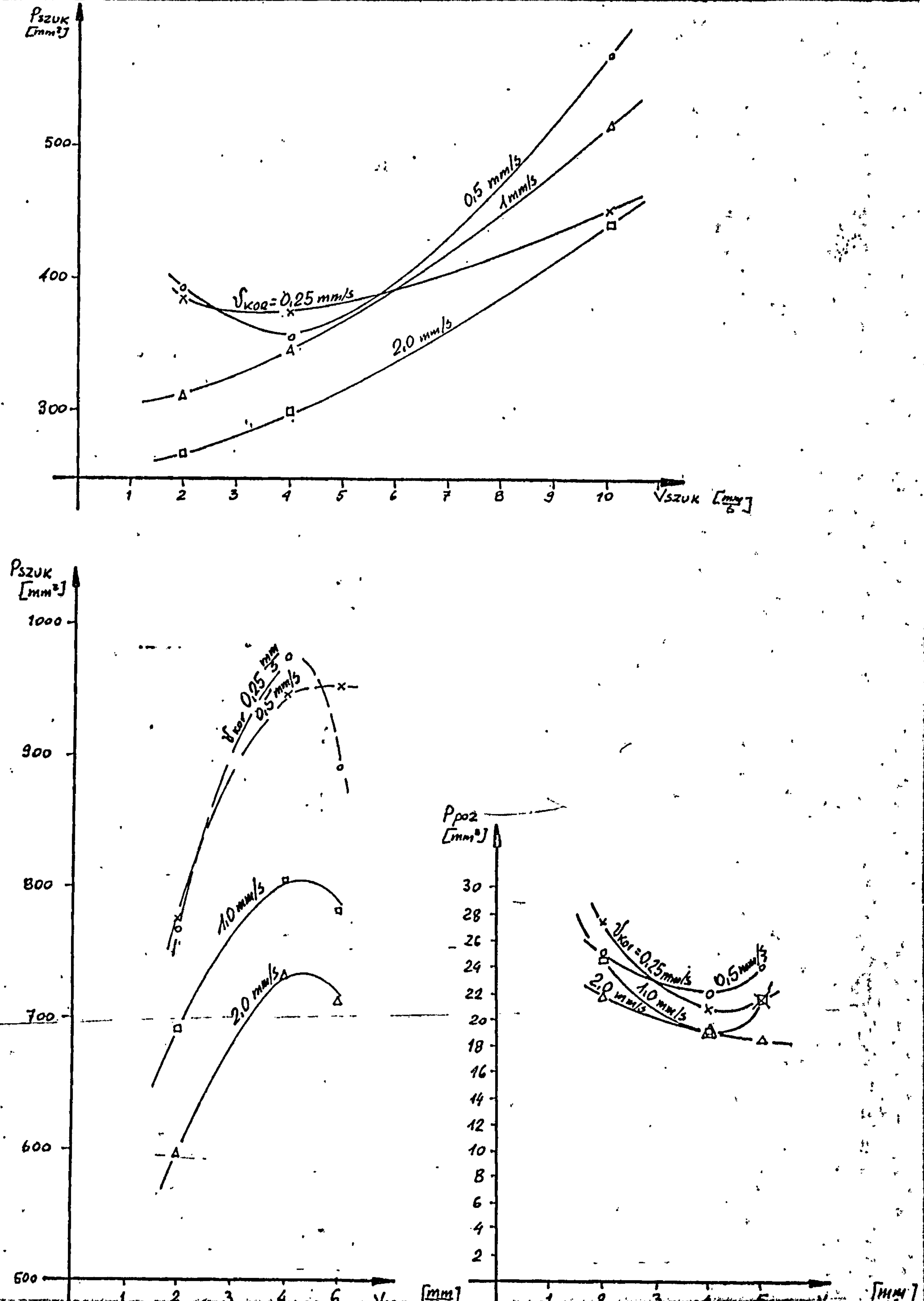
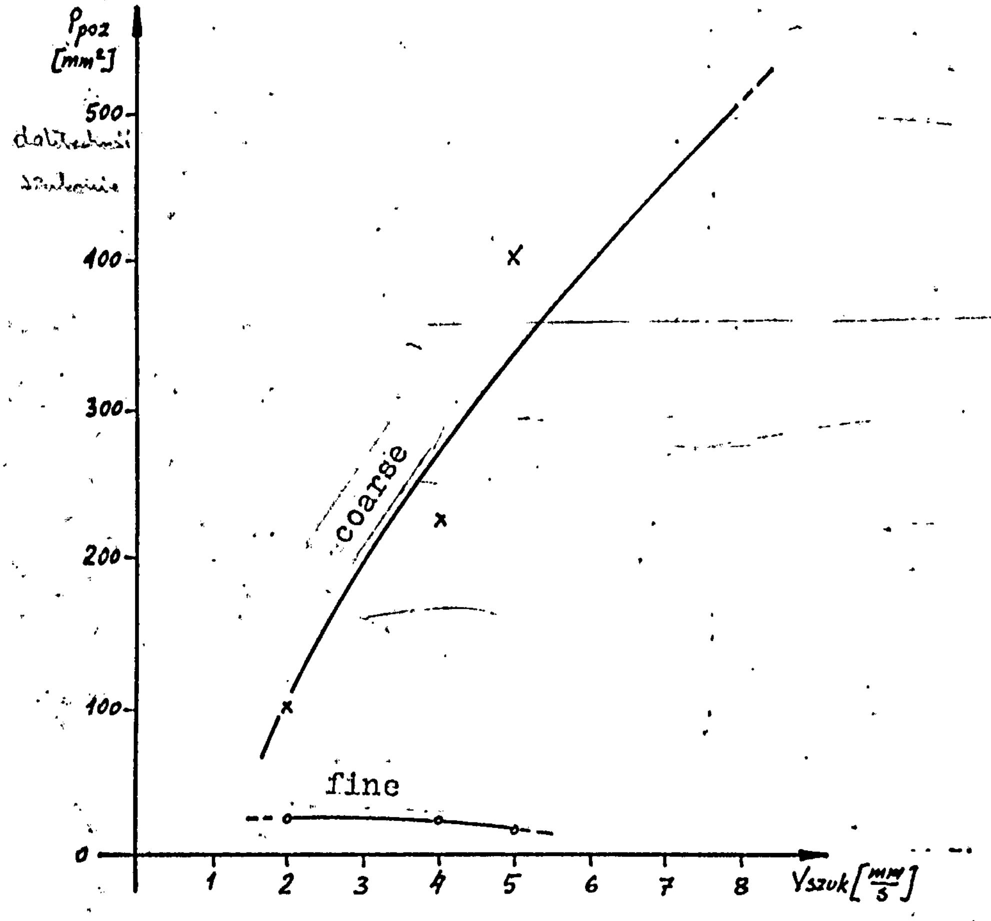


Fig. 31. FINE SEARCHING : the influence of searching speed V_{szuk} and the correction vector V_{kor} on grinding off the touched surfac... /+ ... tests/ and on the ...



Rys. 4. COARSE and FINE SEARCHING : the comparison of searching accuracy of the tool for various searching speeds.

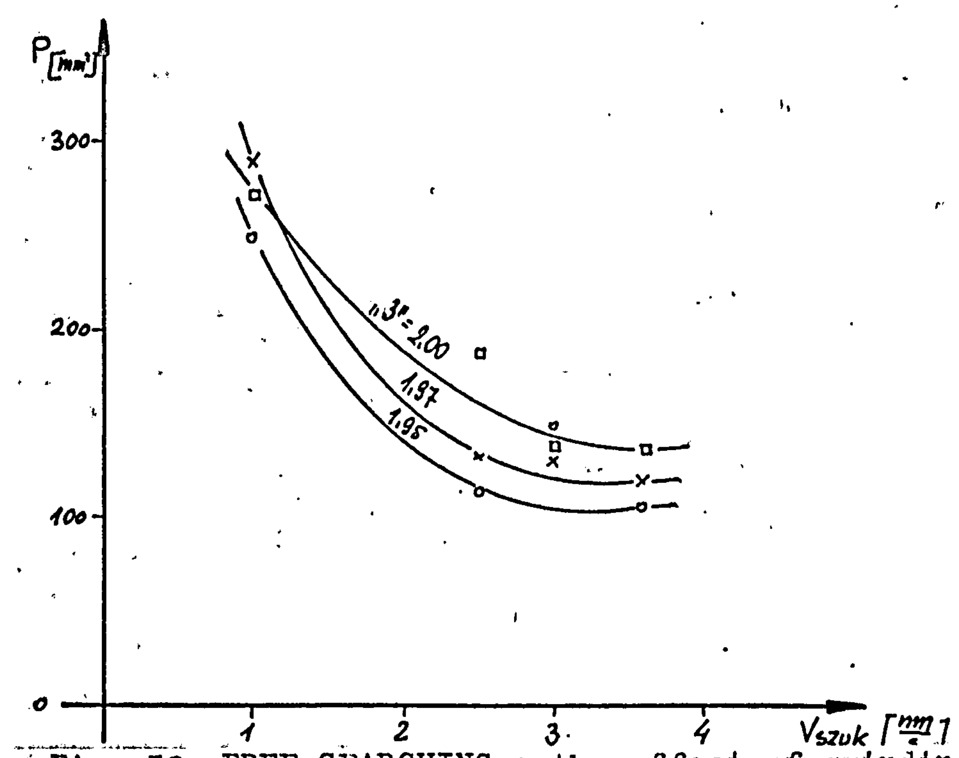


Fig. 32. FREE SEARCHING : the effect of grinding off the touched surface in function of the treshold 3 setting and the searching speed.